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ENTRAINMENT MOISTURE SEPARATORS FOR FINE (1-10 μ) WATER-AIR-STEAM SERVICE: THEIR PERFORMANCE, DEVELOPMENT AND STATUS

by

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NOTICE

ACKNOWLEDGMENT

MSA wishes to thank those many companies and their representatives who contributed their valued time and information on the various aspects of fine-particle entrainment, its generation, measurement and removal. We hope that all infdrmation used has been properly presented in the manner intended and regret being unable to present fully all information submitted.

Our particular gratitude is extended to those suppliers-who submitted entrainment separators, candidate media, and other hardware for this test evaluation program; to Humphrey Gilbert and Marshall Mills of the AEC for theirguidance; and to those at MSA whose efforts are represented in this report.

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ABSTRACT

There is a need for moisture separators that are at least 99% efficient in removing entrained water particles in the 1-10 micron (μ) range from an air stream. This program was conducted to determine if commercially available separators were efficient in this range -and, if they were not, to develop .a new type of separator -which would satisfy the requirements.

Five commercially available entrained. moisture' separators were tested for performance in the 1-10 micron particle-size range. The MSA Type G and the AAF Type T separators were greater than 99% efficient in removing particles in this range fromatmospheric to. PWR post-accident (incident) conditions. The York Type 321 SR separator failed to contain the separated water within the drains of the unit and re-entrainment occurred. The Farr Type 68-44ZH and the Monsanto baffle-type 'separators were inferior because of visible and measured penetration.

MSA test details and results are summarized in -this report. Survey results; presenting-the status 0% entrainment separators and--media for 1-10 micron service, together with methods of measuring and generating particles in this range, have been previously reported.[1,2]

ENTRAINED MOISTURE SEPARATORS FOR FINE PARTICLE WATER-AIR-STEAM SERVICE: THEIR PERFORMANCE, DEVELOPMENT AND STATUS

1. INTRODUCTION

The objective af this effort was to determine-the availability of entrained moisture separators which are efficient in removing water droplets in the 1-10 micron (μ) size range from an air-stream. The MSA acceptance criteria for moisture separators operating at PWR post-accident (incident) conditions were: 99+% removal of water-particles in the 1-10 micron range as determined by measurement and visual observation, a rated flow of at- least 1000 SCFM, and a pressure drop of approximately 1 in. water column (wc) at rated flow. If there were no commercial separators which could perform satisfactorily, ane was to be developed. While many applications, such as acid-plant effluents[3], require high-removal efficiency in the submicron particle-size range-and standard process requirements, such as distillation[4], commonly depend upon particle separation in the high, 10-1000 micron size range, many applications remain particularly for the intermediate 1-10 micron size range. One of these would be for improved performance in separating entrainment from steam to the-low pressure turbine of nuclear-powered naval ships.[5] Another would be-for removal of moisture from gas to catalytic recombiners and similar systems of this type in nuclear power plants, One of the most publicized current applications is for use in the air-cleaning systems in the containment of boiling or pressurized water reactors.[6,7,8,9]

Pressuriied water reactor (PWR) systems for the generation of electric power normally provide several containment air-cleaning systems using moisture separators for the protection of high efficiency particulate air (HEPA) filters, charcoal adsorbers, and other components in those systems. Many of these air-cleaning systems are reserved fox emergency service in the event of loss of coolant which may-occur upon rupture of a major component or piping in the PWR. Incident conditions of elevated pressure and temperature may occur within seconds and may last for a few hours to several days before being adequately suppressed by recirculating air-cleaning systems which cool and condense steam and collect solids and gaseous fission products. Although anticipated PWR incident containment conditions, under which entrained separators must operate, vary somewhat over the many installations, Table 1 illustrates some of the maximum levels expected. The pressure-temperature values for Indian Point-2 Reactor were selected as typical for testing on this project.

Initial phases of this effort included a review of all available literature and data on entrainment separators, particular for the 1-10 micron water droplet service range. When it became

TABLE 1 - MAXIMUM INCIDENT OPERATING CONDITIONS
TYPICAL PWR NUCLEAR REACTOR CONTAINMENTS

	SAVANNAH RIVER[7]	CONNECTICUT YANKEE[5]	INDIAN POINT-2[3]	TURKEY POINT-3,4
erature, F	212	261	271	283
sure, psig	Atmos.+ System ΔP	40	47	59
sure Surge	7-8 times rated flow		14 in. WC	
ainment:				
ading, lb/1000 CF	1.0	8.0	0.35	1.0
Type	Condensed Steam	Sprays plus Condensed Steam	Sprays plus Condensed Steam	Sprays plus Condensed Steam
rator Duty:	For HEPA Protection	For HEPA Protection	For HEPA Protection	For HEPA Protection
noval Efficiency	99.9%		99.9%	99.9%
oplet Diameter	1-10 μ (calculated)		(Not specified)	1 μ
Method	Steam Condensed in Air	Hydraulic Sprays 2400 μ MVD	Hydraulic Sprays 580 μ MVD	Hydraulic Sprays 580-70 μ MVD
rator Used	York 321 SR	AAF Type T	MSA Type G-3	MSA Type G-5

apparent that very little information was available. for separators in this range, the literature survey1 was broadened to include available information on the measurement and generation of water droplets in this range. Similarly, a survey[2] of commercially available separators was broadened to include suppliers of potentially effective media for the 1-10 micron particle size range.

Survey results revealed that the only practical approach for water particle analysis in the 1-10 micron size range readily adaptable to separator efficiency tests was the cascade-impaction method. Pneumatic atomizing nozzles offered the best hope for geneiating appreciable bulk quantities of-1-10 micron-particle size entrainment for test purposes.. Five commercial separators were purchased for test performance evaluation particularly in the 1-10 micron size range. These units were the MSA Type G-5, AAF Type T, York Type 321 SR, Farr Type 68-44MZZ, and a Monsanto standard baffle-type separator.. Of these, two exhibited satisfactory efficiency in the-1-10 micron range, so that development work was not needed. Test procedures, equipment, and results are presented in the body of this report.

2. SUMMARY

Indications of the response of the several separators to liquid particles of various sizes included: 0.3 - 0.6 - 1.1 micron DOP* penetration measurements; 2.5 - 10 micron impactor fraction sampling; manufacturer's rating of entrainment generating nozzles: measurement of entrainment removed within the separator, collected in the downstream duct, collected by the downstream HEPA, and by visual observation of the challenge and effluent streams: DOP, or other calibrated stable particle tests, particularly in the 0.6 - 1.1 micron size, serve as a rapid index to expected separator efficiencies in the lower particle size range. Impaction sampling-offers the best known currently available method for characterizing f-10 micron-particles.

MSA test results of the five commercially available separators can be summarized as follows:

The MSA Type G-5 moisture separator was greater than 99% efficient in removing water particles in the l-10 micron range at mixed entrainment loadings up to 6.7 lbs/1000 cu ft: from near-saturated air streams, ranging from ambient to elevated conditions of 271 F and 47 psig. No penetration was visible or measured in the 2.5 - 10 micron range: 0.6 micron DOP penetration was 80% and 0.3 micron DOP penetration was 96%.

The AAF Type T entrainment separator was similarly acceptable for entrainment removal service adequate for HEPA filter protection service in the l-10 micron range at mimed entrainment loadings up to 6.5 lbs/1000 cu ft. No penetration was visible or measured in the 2.5 - 10 micron fraction; DOP penetratian was 93% far 0.6 micron and.95% for 0.3 micron. Removal of the bulk of large particles, without appreciable increase in differential pressure (ΔP), can be attributed to the baffled inlet section. The upper temperature limit is not known; however, at 271 F, the binder in the glass was observed to darken the glass and color the water droplets clinging to fiber streamers in the effluent air stream. Water leaked out of both lower welded corners at the rear of this separator. These leaks were sealed with a silicone adhesive far test operation.

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* Penetration measurements using Dioctylphthalate (DOP) aerosols are common practice in testing of high efficiency particulate air filters. It was adapted here to secure a non-destructive comparison of potential. performance.

The York Type 321 Sr separator was judged unacceptable for normal HEPA protection service when used as supplied because of the re-entrainment from the downstream face, as described bel No fine entrainment penetration was visible or measured in tie 2.5 - 10 micron range at ambient conditions. The DOP penetration was 69% for 0.6 micron and 93% for 0.3 micron, but the differenti pressure was 1.29 in. WC at rated flaw at ambient conditions which -exceeds-the Savannah River specifications of 0.95 ± 0.35 in WC. Penetration measurements of 1.1 micron DOP for twelve layers of Teflon media at the same inlet velocities and pressure loss were 56% for the York media and 38% for comparable MSA Teflon med The York separator was not selected for testing at incident condi tions since in the ambient, horizontal gas-flow tests with fine entrained particles,-the separated-liquid. flowed to the downstrea face of the separator and was blown off or re-entrained from the lower two-thirds of the downstream separator face. Two modes of re-entrainment were observed. The pool which accumulated in the bottom of the frame simply overflowed the frame and the air shear some large-drops from the top surface of the pool. These fell rapidly but had some horizontal motion imparted by the air flow. Other drops -- also larger than the entering dropiets -- fell fr -points higher up an the downstream face of the separator, Only a small portion of the removed water was contained within the separator case and drained through the two 1/4 NPS nozzles provid in the bottom of the separator case. The percentage of water removed from within the separator case varied from 36% at 0.24 lb/ 1000 cu ft entrainment loading to 15% at 1.23 lb/1000 cu ft. The performance- properties of the York Teflon media have been well publicized7 and because of the limited radiation resistance of Teflon on exposure to 10^4 rads, coupled with the poorer performan at ambient conditions, the decision was made not to test the York separator at incident conditions.

The Parr Type 68-44MZH separator 'allowed penetration of visible entrainment which was also detectable by impactor measure ments. DOR penetration measurements gave 99% at 0.6 micron, indi cating very little attenuation and essentially complete penetrati of 100% at the 0.3 micron size. Removal. efficiencies greater tha 99% were found for 100 micron mean volume distribution (MVD) particles up to a loading of 6.5 lb/1000 cu ft. Some re-entrain lowered this to 90% with 10 micron MVD loading at 0.03 lb/1000 cu Farr rates this separator primarily for solids with slightly lowe efficiencies ranging from 99% at 20 micron to 40% at'P.5 micron size particles. Since this separator gave measurable penetration in the 1-10 micron range at ambient conditions, no tests on the Farr separator at incident conditions were made.

The Monsanto baffle-type separator was found least suit for protection of HEPA filters in the l-10 micron range. Appreci entrainment penetration was visible and detectable by impactor measurements when using the 10 micron MVD challenge stream. DOP penetration values were 99% at 0.6 micron and 100% at 0.3 micron. Overall entrainment-removal efficiencies ranged from 99% at 6.5 lb/1000 cu ft loading with 100 micron MVD entrainment to 85% at 0.04 lb/1000 cu ft loading with 10 micron MVD size entrainment, Since 1-10 micron response was poor, no tests at incident conditions were made on this separator.

Atomizing nozzles proved to be a satisfactory method of generating controlled quantities of water particles of known sizes. Condensing steam at elevated conditions did not generate comparable bulk quantities. Using extended surface cooling of steam did not generate measurable amounts of small particles and decreased the wet-bulb temperature under MSA t&t-conditions.

Humidity approaching saturation values is difficult to control, not accurately measurable at incident conditions with currently available equipment, and may influence small particle life to a greater degree than anticipated by calculations as discussed in Section 6.1. Actual PWR incident conditions, however, would rarely approach saturation conditions except in the immediate vicinity of the pressurized water release: Cooling by containment structure, equipment and sprays, together with pressure-drop changes, contributes to lowering the humidity of the air entering the moisture separators to a value below saturation.

3. TEST FACILITIES

MSA has many applicable test facilities currently in operation: thus basic equipment for measurement of flow rate, pressure drop, DOP penetration, etc., were readily available. Modification of the MSA system for entrainment testing was necessaii for the more detailed efficiency performance study desired in the 1-10 micron particle size range. Special apparatus was provided for generating and measuring liquid particles in this size range. A more detailed description of the pertinent test facilities used is presented in the following subsections.

3.1 ENVIRONMENTAL TEST FACILITY (ETF)

The ETF was designed and fabricated especially for test operation of full-sized entrainment separators, HEPA filters, charcoal cells, and other components, over a wide range of operation from ambient to elevated conditions (PWR incident and above). The basic equipment will be described in the following paragraphs. However, it was necessary to make the following modifications to accommodate the testing of this project:

A. Addition of two stream sampling stations for impactor classification of particle size,

C. Addition of a heat exchanger for studying particle size of entrainment resulting from condensing steam in this manner and for humidity control.

D. Revised-system temperature control and design and location of heating-coils to maintain the desired high humidity with least variation. This eliminated the dehumidification which would occur from the direct injection of dry, superheated steam at a slightly higher pressure.

E. Addition of a pneumatic fine-spray nozzle system for generating entrainment particles in the l-10 micron size range.

F. addition of hydraulic nozzles in the smallest particle generating range available (300 micron) to permit tests with Large bulk entrainments to establish separator capacities.

G. Increased separator-drain and penetration-measurement provisions-were added to accommodate the increased-bulk,

H. Addition of thermocouples for complete system temperature profiles.

Figures 1 to 11 of this report give a schematic and pictorial view of the ETF. The 4-foot diameter shell is fitted with a 2-foot square inner duct with recirculation of the entrainment atmosphere in the annular space. A variable speed fan takes gas from the inner duct at the outlet of the flow nozzles and directs it through tie annular space for return to the inner duct at the opposite end. The gas stream passes over the condensate pool in the annulus where it is heated by mixing with steam from the supply pipe and by the pool which is held at temperature by the same steam addition to maintain a high relative humidity. It then passes through the heat exchanger in the annulus and picks up fine (10 micron MVD and less) entrainment from pneumatic atomizing sprays just before entering the inner duct. Flow passes through the inner duct heat exchanger and can be viewed through the sight glasses (SG-1) at the heat-exchanger outlet. Passage through the hydraulic spray section permits addition cf larger (100 micron MVD) particle size entrainment which can be viewed through sight glasses (SG-2) just before entering the entrainment separator. The entrainment-laden gas stream then passes through the entrainment separator undergoing test. It can be viewed at the

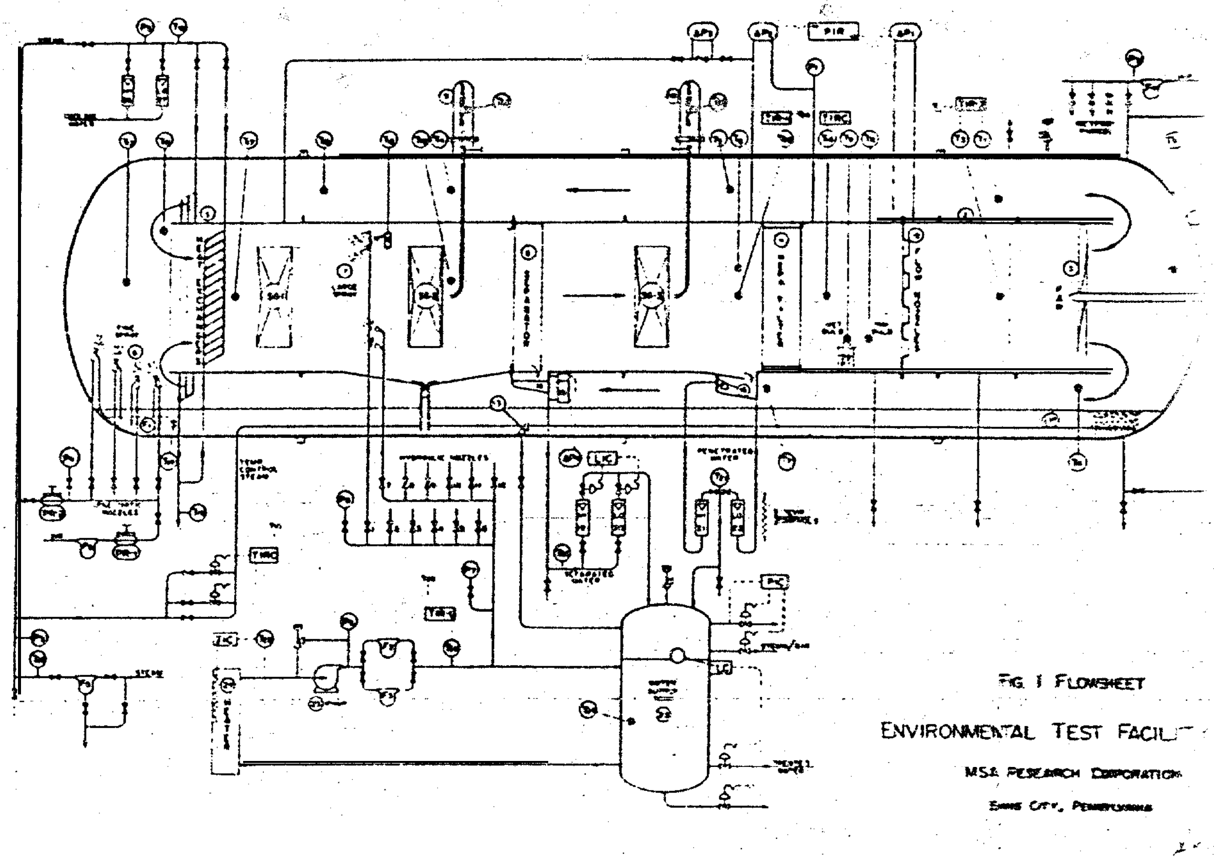

FIG. 1 FLOWSHEET

ENVIRONMENTAL TEST FACILITY

MSA RESEARCH CORPORATION

Evans City, Pennsylvania

1. **Containment Vessel**, 48 in. ø x 10 ft long x 4 sections
2. Annular Duct, 24 in. x 24 in. x 7 **sections**
3. **Fan**, 24 in. **vaneaxial**, ball bearings, **mech seal**
4. **Fan** Drive, variable **3940/1330 RPM**, 25 *HP* motor
5. **Heat** Exchangers, **cooling** or heating, **200,000 Btu/hr**
6. Fine Spray Nozzles, 39 atomizing type **1-A**
7. Large Spray **Nozzles**, 108 hydraulic **type** TX-l
8. **Entrainment** Sevarator, **typical**
9. **Impactor** Particle **Sampler**, upstream
10. **Impactor** Particle Sampler, **downstream**
11. **HEPA** Filter, **MSA Model CU 72920XBBXA**
12. Gas Stream **Flow Nozzles**, 4 x 4.000" **ASME**, Calibrated **with NBS** Plate
13. System **Water** Level Control
14. **Separator** Case Drain Sump
15. Level Gage on Separator **Sump**
16. Separator Penetrated Water **Collection** Sump
17. **Steam** Line *for* System Temperature Control
18. **System** Hater Level Gage
19. **Rotometer** on Separator **Sump**, 1.12 GPX
20. Rotometer *on* Separator **Sump, .094 GPM**
21. Rotometer on Penetration Sump, 1.12 **GPM**
22. Rotometer on Penetration **Sump, .098 GPM**
23. Spray **Water Supply** Tank, 30 gal.
24. Spray **Water** Heater, 3 **KW**
25. **Spray Water Pump**, Turbine, **7-1/2** HP
    10 **GPM @ 145** psi, 300 psig **- 275F max**
26. **Rotometer an Coding Watex**, 20 CPM
27. **Rotometer** on **Cooling Water, 4 GPM**

F_1 Filter for *At* **mizing** Water, cl µ
$F_{2,3}$ Filters *for* **Spray** *Hater, 25* µ
$F_{4,5}$ Pitters *for* **Air, 0.3** µ
F_6 Filter for Steam, S µ

LC **Level Control on Water** Tank
LIC Level Indicator-Controller

P_1 **System** Pressure **@ HEPA outlet**, to 70 psig

PIR Pressure **Indicator-Recorder**,
PIC **Pressure Indicator-Controller**,

PR-1 Pressure **Regulator for Air** RI---
PR-2 **Pressure** Regulator **for Steam**,

SG_1 Sight Glass **at HX Outlet**
SG_2 Sight Glass **at Separator Inlo**
SG_2 Sight Glass **at Separator Out**

T_1 **Return Gas Temp, above Flow**
T_{1A} **HEPA Outlet Temp, on TIRC**
T_2 Fan **Outlet Temp, on TIR-2,**
T_{2A} Spray **Water Supply Temp, on**
T_{2B} **HEPA Inlet Temp, on TIR-1**
T_3 **Flow Nozzle Outlet Temp**
T_4 Return **Gas Temp, below Fan**
T_5 Return **Gas Temp, above HEPA**
T_6 **HEPA Inlet Temp**
T_7 Return Gas **Temp, below HEPA**
T_8 **Dry Bulb Temp @ HEPA Outlet**
T_9 Wet **Bulb Temp @ HEPA Outlet**
T_{10} Separator **Inlet Temp**
T_{11} **Return Gas Temp, above Separa**
T_{12} Spray Water **Temp, instream**
T_{13} **Return Gas Temp, above Fine**
T_{14} **Atomizing Spray Water Temp**
T_{15} **Return Gas Temp, at top inlet**
T_{16} **Return** Gas **Temp, above HX outl**
T_{17} **HX Outlet Temp**
T_{18} Cooling **Water Temp into HX**
T_{19} Cooling Water **Temp out of HX**
T_{20} Separator **Case Drain Water Te**
T_{21} **Separator Penetrated Water Te**
T_{22} Upstream **Sampler Temp**
T_{23} **Downstream Sampler Temp**
T_{24} Spray Water **Supply Tank Temp**
T_{25} Spray water **Heater Outlet Temp**
T_{26} **Steam Supply Temp**

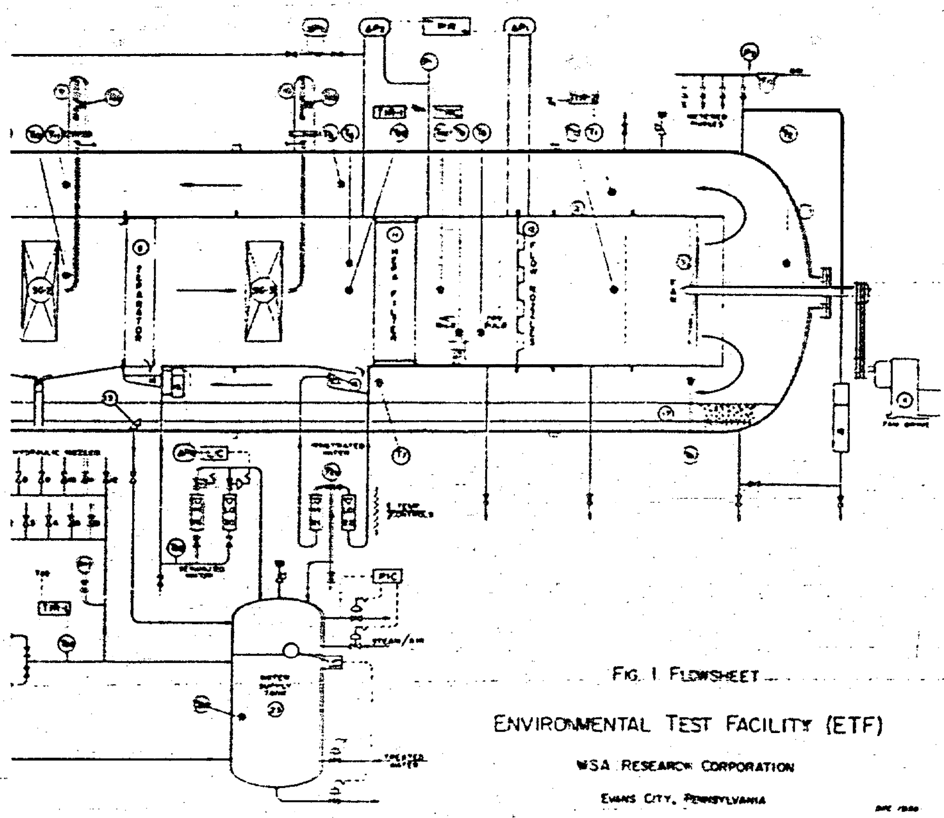

FIG. 1 FLOWSHEET

ENVIRONMENTAL TEST FACILITY (ETF)

MSA RESEARCH CORPORATION

EVANS CITY, PENNSYLVANIA

AK-2516-34

ft long x 4 *sections*
sections
ngs, mech seal
M, 25 HP motor
ng, 200,000 Btu/hr
type 1-A
t-TX-1

am
eam

" ASME,

ion Sump
Control

GPM
GPM
.2 GPM
'8 GPH

P
max
M

PIR Pressure Indicator-Recorder, to 4"/10" WC
PIC Pressure Indicator-Controller, to 100 psig

PR-1 Pressure Regulator for Air Atomization
PR-2 Pressure Regulator for Steam Atomization

SG_1 Sight Glass at HX Outlet
SG_2 Sight Glass at Separator Inlet
SG_2 Sight Glass at Separator Outlet

T_1 Return Gas Temp, above Flow Nozzles
T_{1A} HEPA Outlet Temp, on TXRC
T_2 Fan Outlet Temp, on TIR-2, typical
T_{2A} Spray Water Supply Temp, on TIR-1
T_{2B} HEPA Inlet Temp, on TIR-1
T_3 Flow Nozzle Outlet Temp
T_4 Return Gas Temp, below Fan
T_5 Return Gas Temp, above HEPA Inlet
T_6 HEPA Inlet Temp
T_7 Return Gas Temp, below HEPA Inlet
T_8 Dry Bulb Temp @ HEPA Outlet
T_9 Wet Bulb Temp @ HEPA Outlet
T_{10} Separator Inlet Temp
T_{11} Return Gas Temp, above Separator Inlet
T_{12} Spray Water Temp, instream #1D Bank
T_{13} Return Gas Temp, above Fine Sprays
T_{14} Atomizing Spray Water *Temp*
T_{15} Return Gas Temp, at top inlet to HX
T_{16} Return Gas Temp, above HX outlet
T_{17} HX Outlet Temp
T_{18} Cooling Water Temp into HX
T_{19} Cooling Water Temp out of Hx
T_{20} Separator Case Drain Water Temp
T_{21} Separator Penetrated Water Temp
T_{22} Upstream Sampler Temp
T_{23} Downstream Sampler Temp
T_{24} Spray Water Supply Tank Temp Indicator
T_{25} Spray Water Heater Outlet Temp

2

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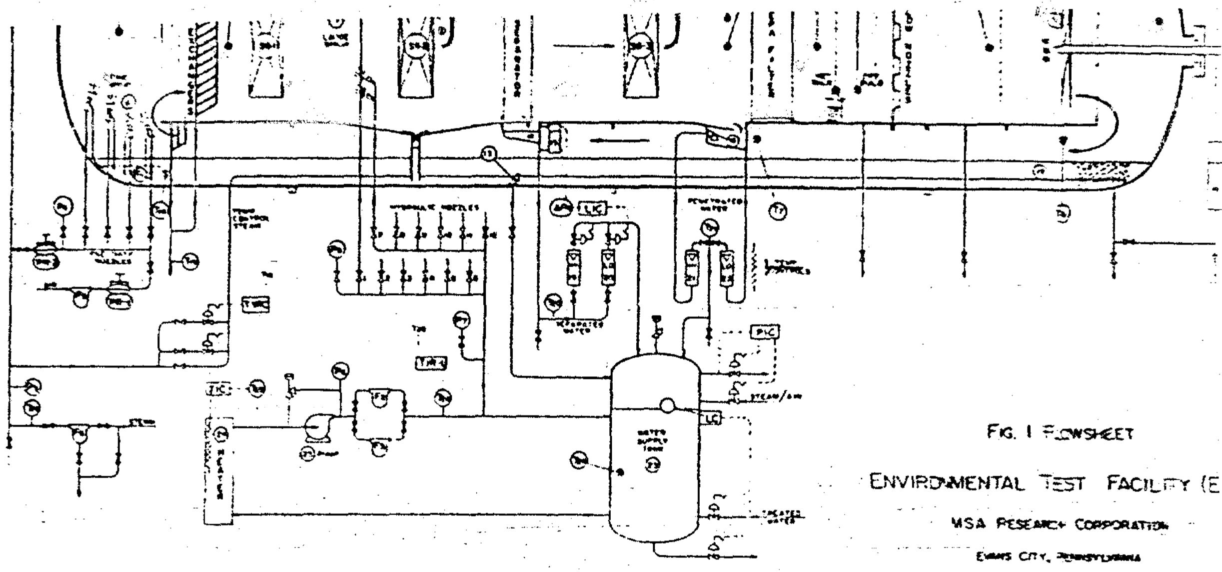


FIG. 1 FLOWSHEET

ENVIRONMENTAL TEST FACILITY (ET

MSA RESEARCH CORPORATION

EVANS CITY, PENNSYLVANIA

AK-25?C

1. Containment Vessel; 48 in. ø x 18 ft long x 4 sections
2. Annular Duct, 24 in. x 24 in. x 7 sections--
3. Fan, 24 in. vaneaxial, ball bearings, mech seal
4. Fan Drive, variable 3940/1330 RPM, 25 HP motor
5. Heat Exchangers . cooling .. .. 200,000 Btu/hr
6. Fine Spray Nozzles, 39 atomizing type 1-A
7. Large Spray Nozzles, 108 hydraulic type TX-l
8. Entrainment Separator, typical
3. Impactor Particle Sampler, upstream
10. Impactor Particle Sampler, downstream
11. HEPA Filter, MSA Model CU 72920XBBXA
12. Gas Stream Flow Nozzles, 4 x 4.000" ASME, Calibrated with NBS Plate
13. System Water Level Control
14. Separator Case Drain Sump
15. Level Gage on Separator Sump
16. Separator Penetrated Water Collection Sump
17. Steam Line for System Temperature Control
18. System Hater Level Gage
19. Rotometer on Separator-Sump, 1.12 GPM
20. Rotometer on Separator Sump, .094 GPM
21. Rotometer on Penetration Sump, 1.12 GPM
22. Rotometer on Penetration Sump, .098 GPM
23. Spray Water Supply Tank, 30 gal.
24. Spray Water Heater, 3 KW
25. Spray Water Pump. Turbine, 7-1/2 BP
 10 GPM @ 145 psi. 300 psig - 275F sax
-26. Rotometer on Cooling Water, 20 GPM
27; Rotometer on Cooling Water, 4 GPJ4

F_1 Filter for At mizing Water, < 1 µ
$F_{2,3}$ Filters for Spray Water, 25 µ
$F_{4,5}$ Filters for Air, 0.3 µ
F_6 Filter for Steam, 5 µ

LC Level Control on Water Tank
LIC Level Indicator-Controller

P_1 System Pressure @ HEPA outlet, to 70 psig
P_2 Air Supply Pressure, 90 ± 5 psig
P_3 Steam Supply Pressure, 65 ± 5 psig
P_4 Air/Steam Pressure to Pneumatic Nozzles
P_5 Cooling Water Pressure, to 60 ± 10 psig
P_6 Pump Discharge Pressure
P_7 -Spray Water Pressure, Manifold inlet
P_8 Spray Water Pressure, Manifold outlet

ΔP_1 System Flow Nozzles pressure drop
ΔP_2 HEPA Filter pressure drop
ΔP_3 Entrainment Separator pressure drop
ΔP_4 Separator Sump Level pressure drop

PIR Pressure Indicator-Recorder, to 4
PIC Pressure Indicator-Controller, to

PR-1 Pressure Regulator for Air Atomi
PR--2 Pressure Regulator for Steam Atc

SG_1 Sight Glass at HX Outlet
SG_2 Sight Glass at Separator Inlet
SG_2 Sight Glass at Separator Outlet

T_1 Return Gas Temp, above Flow Nozz.
T_{1A} HEPA Outlet Temp, on TIRC
T_2 Fan Outlet Temp, on TIR-2, typic
T_{2A} Spray Water Supply Temp, on TIR-1
T_{2B} HEPA Inlet Temp, on TIR-1
T_3 Flow Nozzle Outlet Temp
T_4 Return Gas Temp, below Fan
T_5 Return Gas Temp, above HEPA Inlet
T_6 HEPA Inlet Temp
T_7 Return Gas Temp, below HEPA Inlet
T_8 Dry Bulb Temp @ HEPA Outlet
T_9 Wet Bulb Temp @ HEPA Outlet
T_{10} Separator Inlet Temp
T_{11} Return Gas Temp, above Separator
T_{12} Spray Water Temp, instream #10 Bar
T_{13} Return Gas Temp, above Fine Sprays
T_{14} Atomizing Spray Wats Temp
T_{15} Return Gas Temp, at top inlet to HX
T_{16} Return Gas Temp, above HX outlet
T_{17} HX Outlet Temp
T_{18} Cooling Water Temp into HX
T_{19} Cooling Water Temp out of HX
T_{20} Separator Case Drain Water Temp
T_{21} Separator Penetrated Water Temp
T_{22} Upstream Sampler Temp
T_{23} Downstream Sampler Temp
T_{24} Spray Water Supply Tank Temp Indic
T_{25} Spray Water Heater Outlet Temp
T_{26} Steam Supply Temp

TIC Temp-Indicator-Controller on T_{25}
TIR-1 Temp-Indicator-Recorder on T_{2B}, $T_{..}$
TIR-2 Temp-Indicator-Recorder on $T_{1,2,3}$ -
TIRC Temp-Indicator-Recorder-Controller

Valve, manual

Valve, instrument controlled

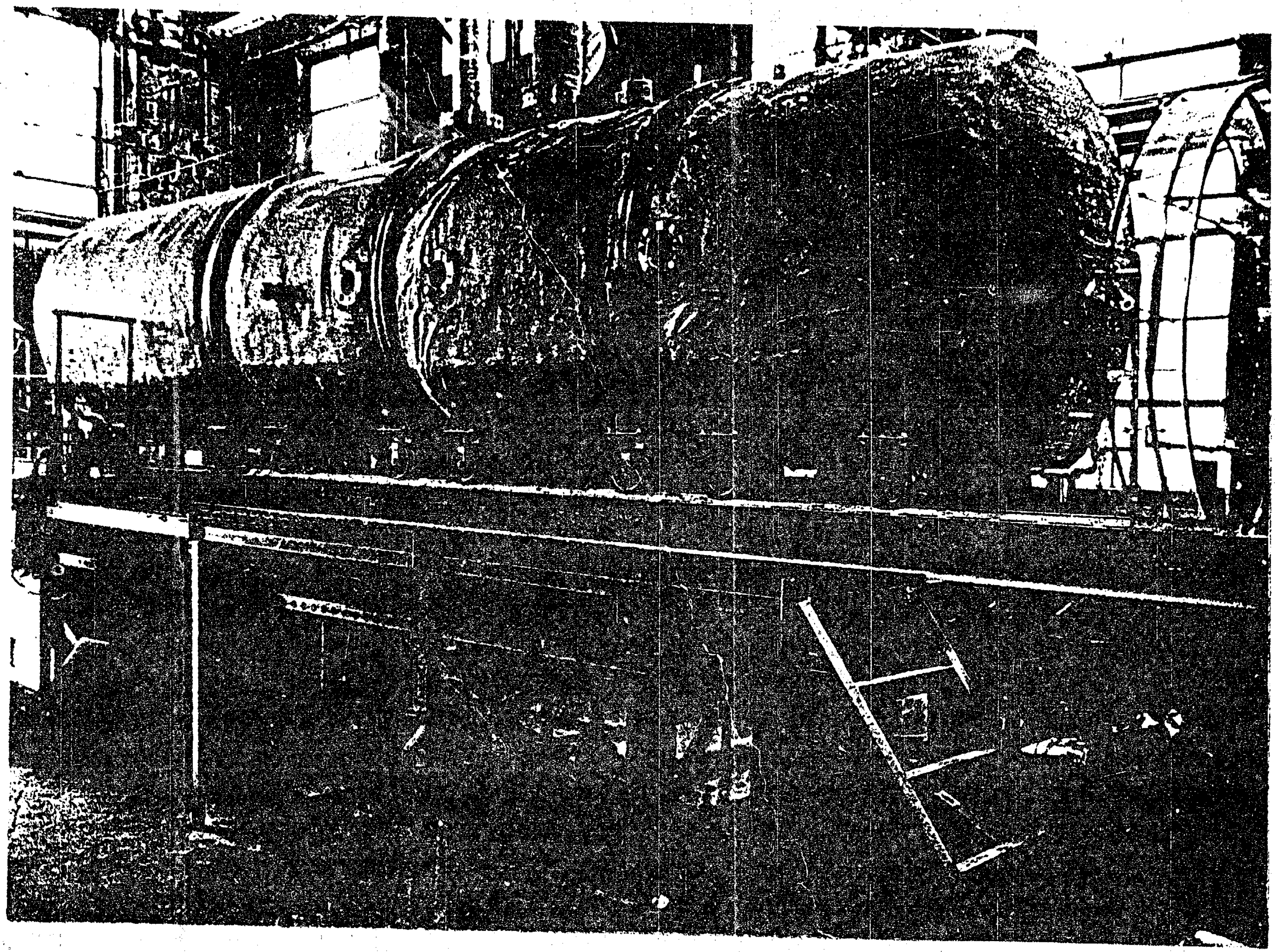
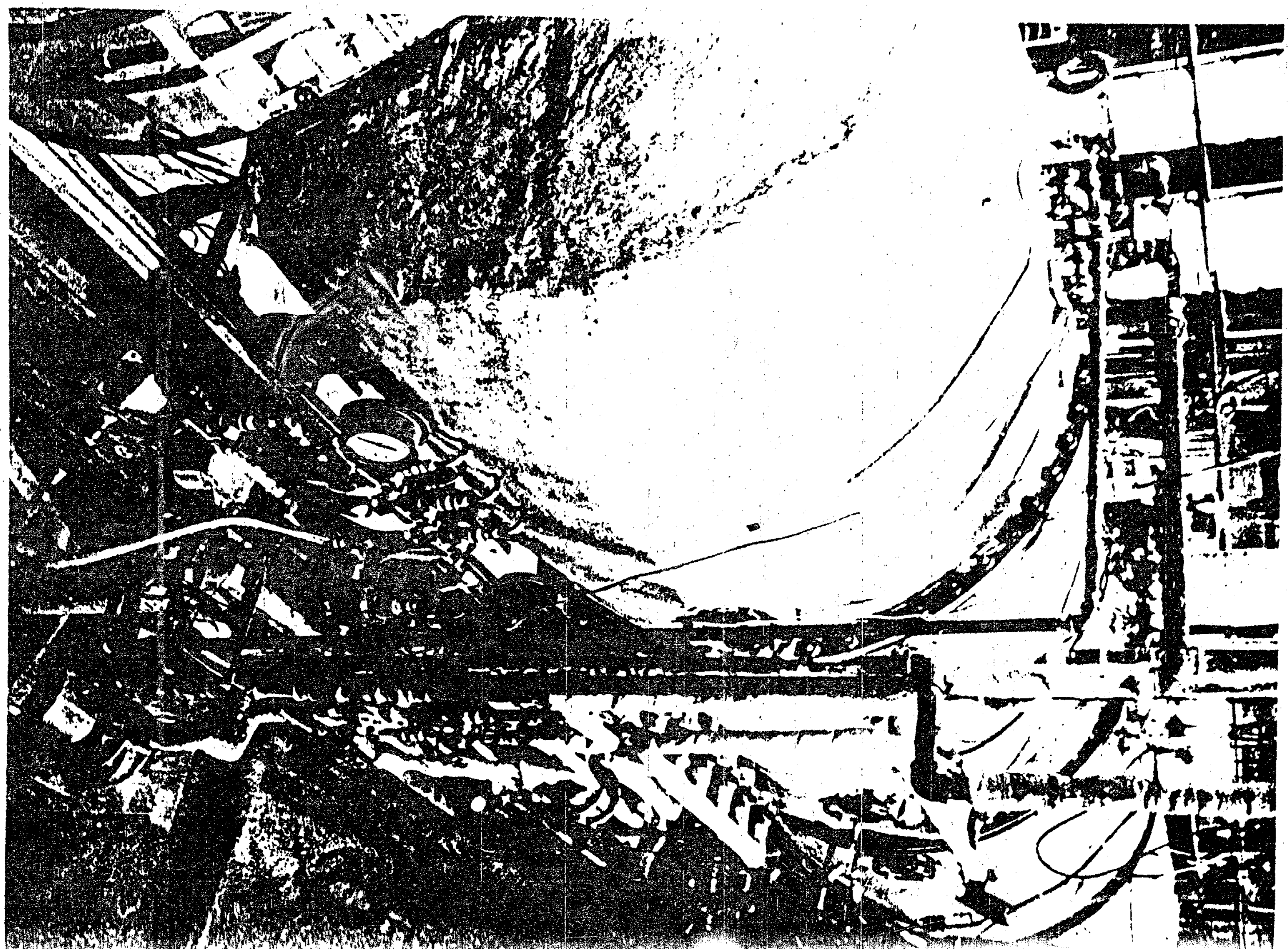


FIG. 2 [illegible]



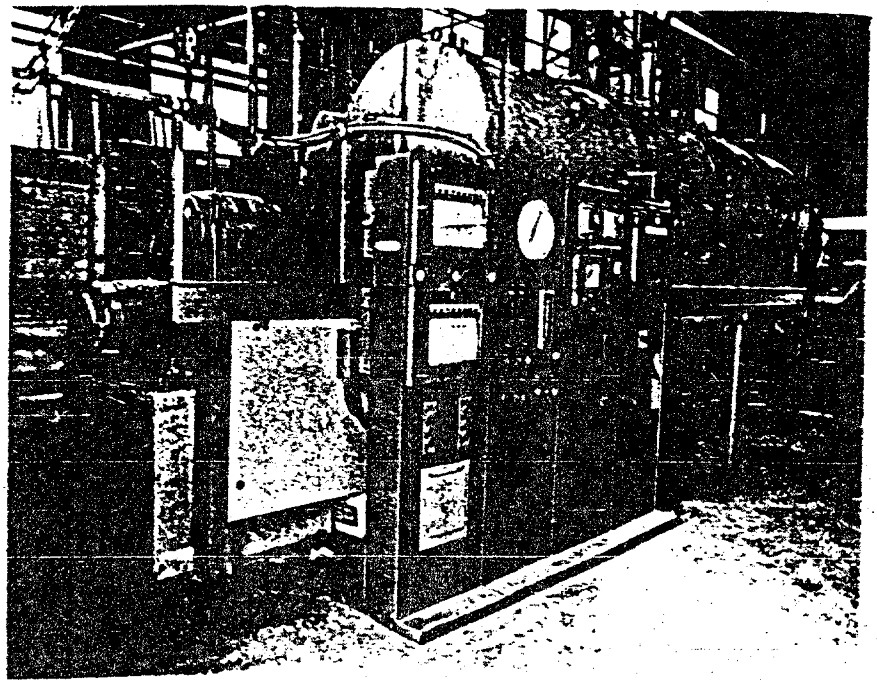


FIG. 4 - ETF, VIEW FROM CONTROL PANEL

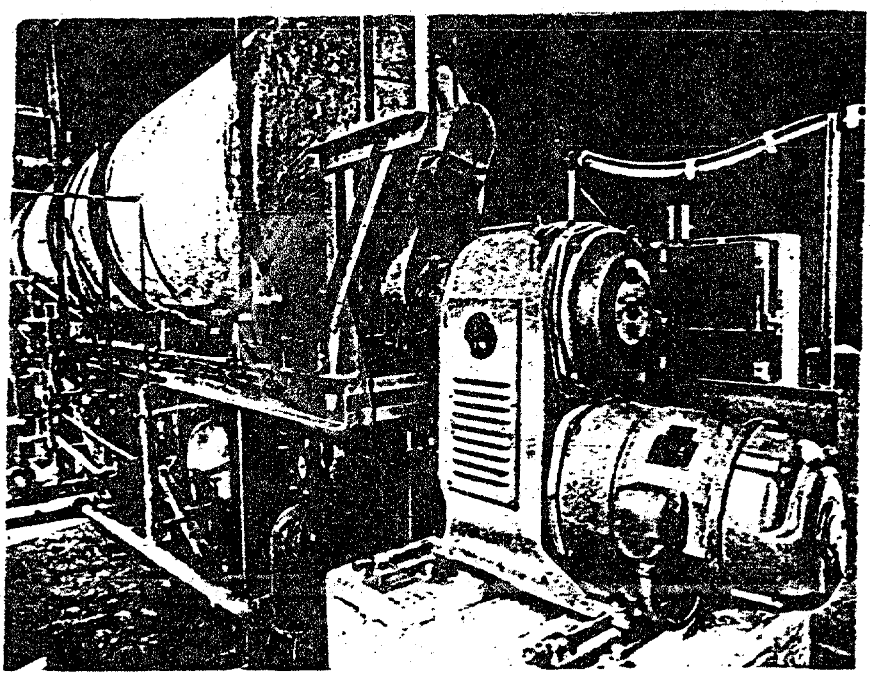
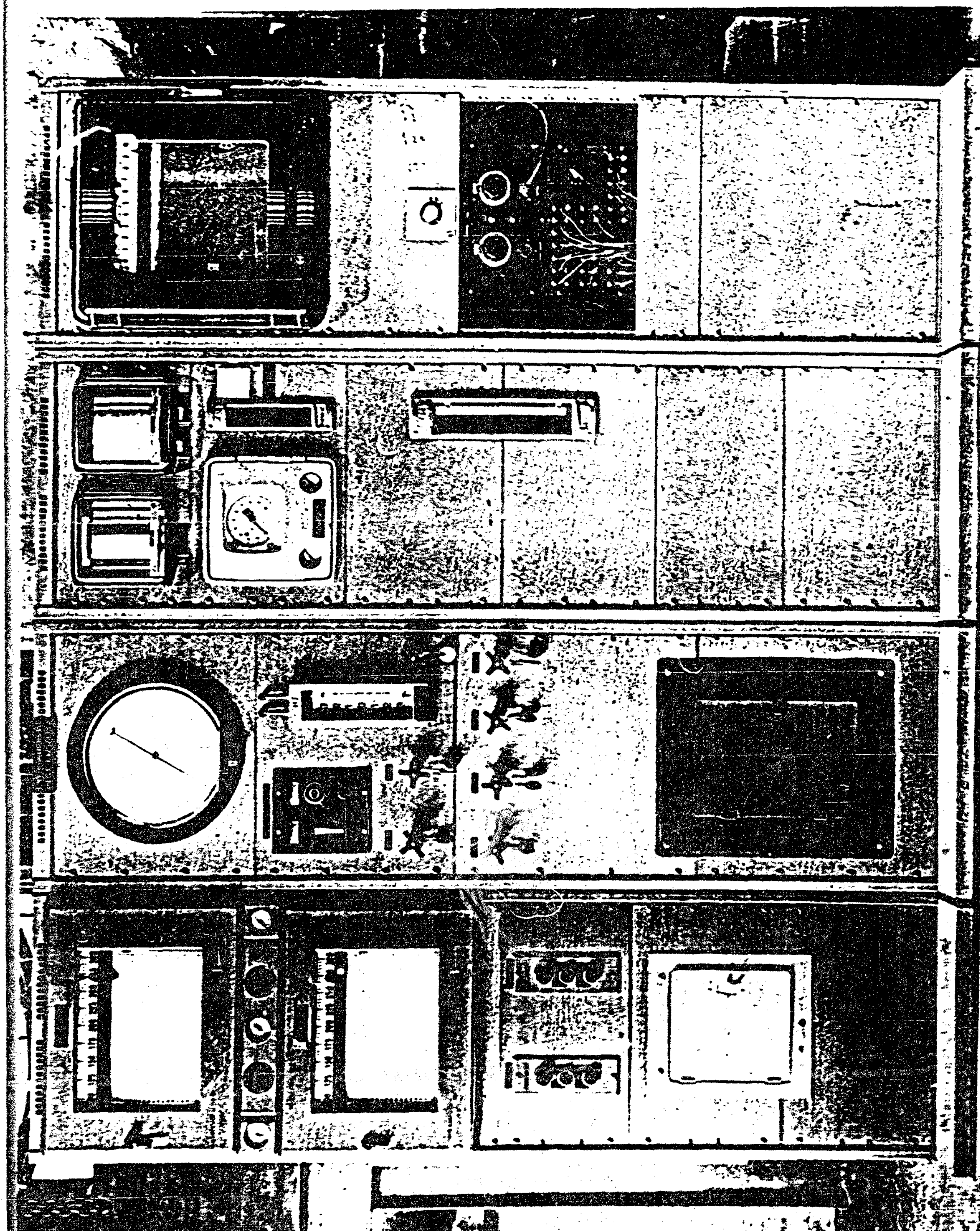


FIG. 5 - ETF, VARIABLE SPEED-DRIVE FOR FAN SECTION



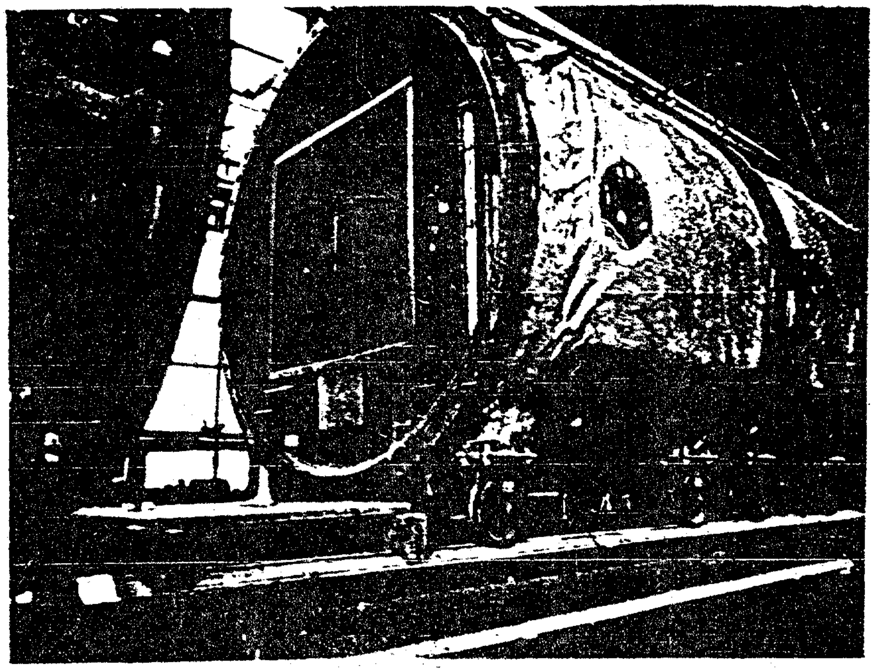


FIG. 7, - ETF, SEPARATOR INSTALLATION AREA

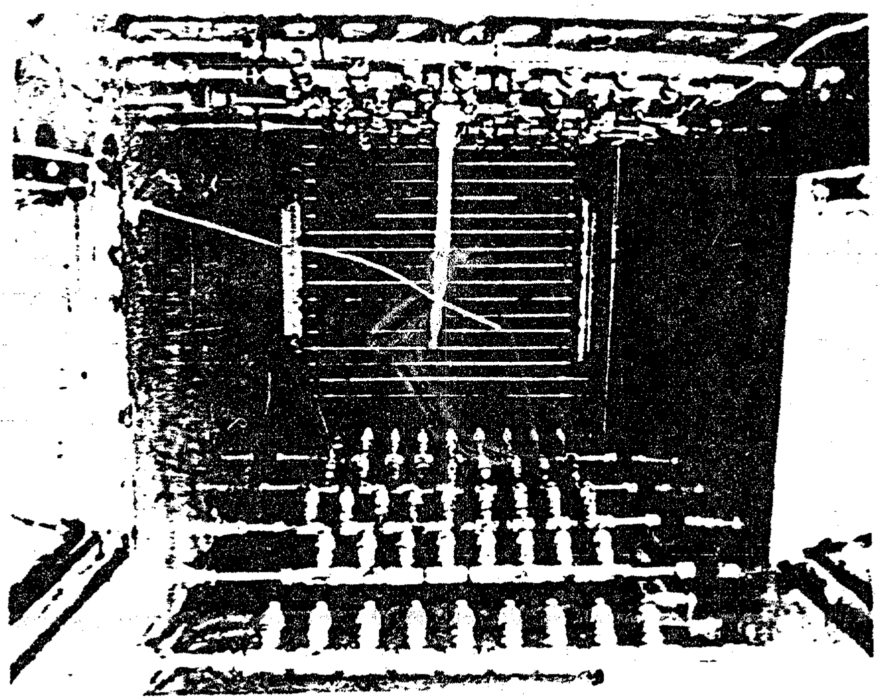
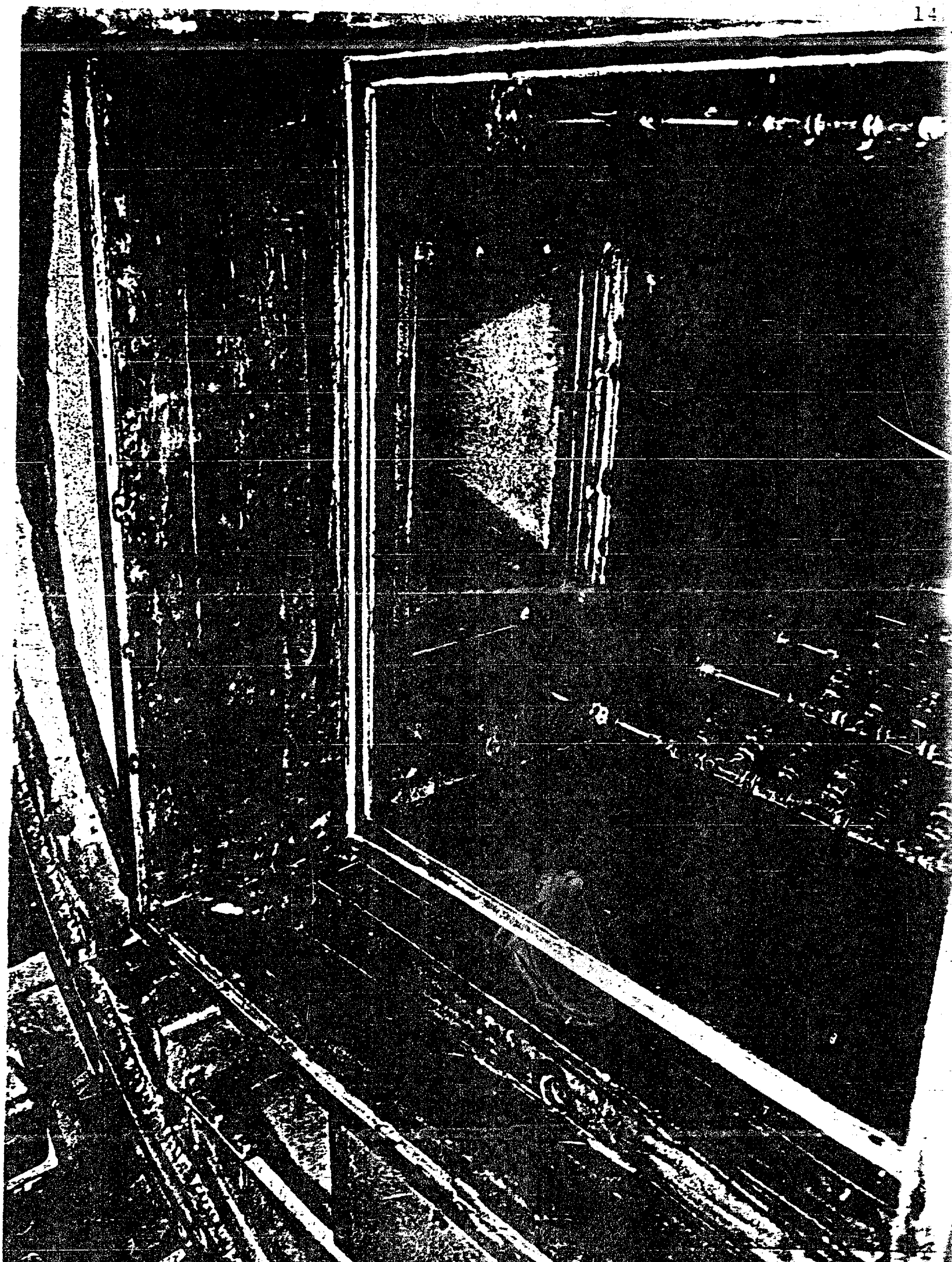


FIG. 8 - ETF, SPRAY NOZZLE AND HEAT EXCHANGER SECTION UPSTREAM OF SEPARATOR



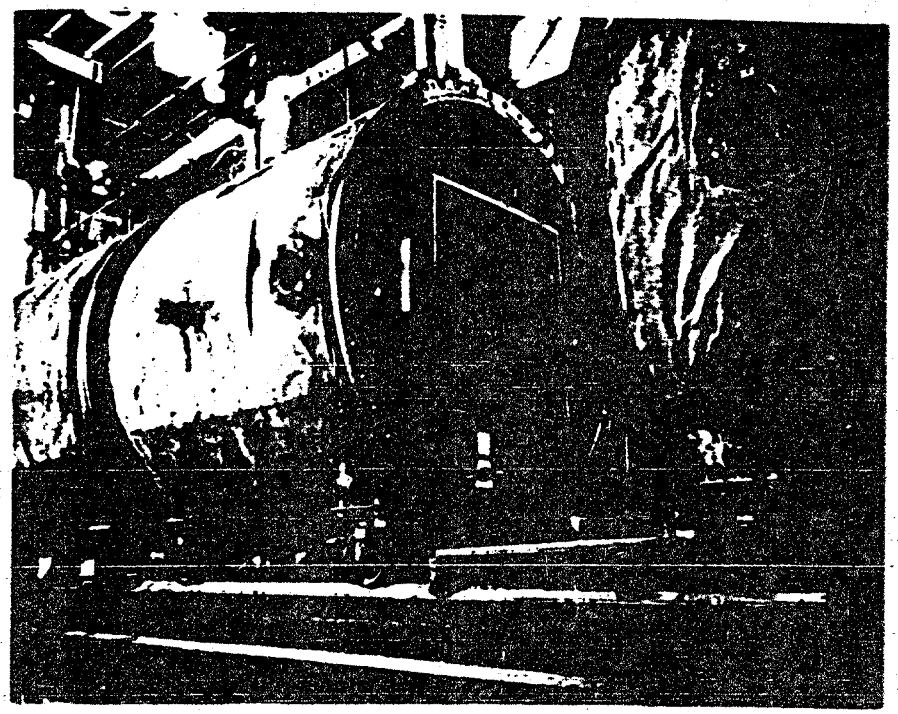


FIG. 10 - ETF, HEPA INSTALLATION AREA

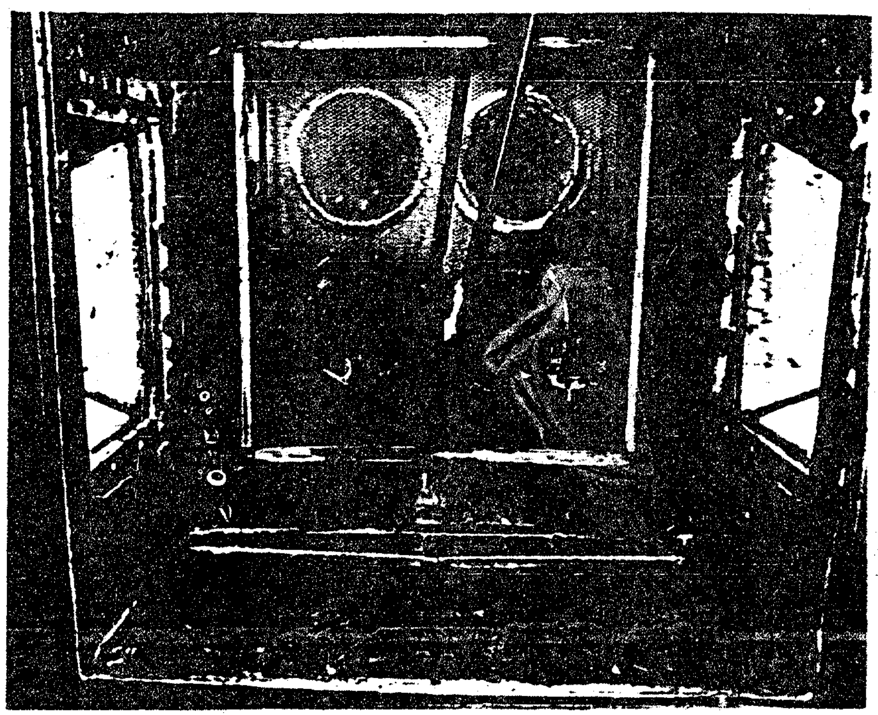


FIG. 11 - ETF, FLOW NOZZLES DOWNSTREAM OF HEPA - PENETRATION SUMP, HEPA POSITION AND FLOW NOZZLES

gas is then returned to the fan through the gas-flow metering nozzles for recirculation.

Auxiliary provisions include plant steam and water for heating and cooling; treated water, recirculated and measured in the entrainment section: instrumentation for measurement and control of system gas flow, pressure, and temperature. Sampling provisions across the separator permit analyses for separator efficiency measurements of the small (2.5 - 10 micron) particle size fraction. Submicron particles penetrating the separator will be captured by the HEPA for measurement by weight gain, Larger particles resulting from re-entrainment will generally drop out of the gas stream and be collected for measurement in the separator penetration sump (16). The major portion of entrainment should be removed by the separator for collection and measurement from the separator case-drain sump (14). Additional ETF component description and data are presented in the subsections following.

3.1.1 Containment Vessel

Drawing:	MSA AK-2516-17, General Assembly Reference
Code :	ASME Section VIII
Rating:	100 psig at 400 F
Size:	48 in. OD x 18 ft 11 in. Pang, exclusive of nozzles
	252 sq ft surface area, shell and head
	226 cu ft total volume
Sections:	4 - flanged; fitted with casters for horizontal support track mounting
	1 - 8 in. long plexiglass section for ambient service
Nozzles:	-100 - various sizes, 1/2 in, through 6 in.
Accessories:	Annular duct, each section, 24 in. x 24 in. *minimum* -inside dimensions
	Fan assembly
	Flow nozzles with straighteners
	Heat exchangers
	Test components and service provisions

Materials: Wetted parts of containment sections and their accessories - generally Type 304 stainless steel. Some trim items of other non-reactive materials or of coated materials to protect system from contamination under test conditions.

3.1.2 Spray Nozzles

Manufacturer: SPRAYING SYSTEMS COMPANY

Fine Sprays:

Type: -- -Pneumatic atomizing
1-A spray set-up
1650 fluid nozzle
64 air nozzle
1/4 J assembly

Service: For finest particle size available, including a portion in the 1-10 micron range

Atomizing gas: Air or steam to 400 F

Fluid: Siphoned or gravity feed water-filter& to 1 micron

ETF use: 39 nozzles in four banks - two of 13 each, one of 8, and one of 5

Atomizing pressure 5-10 psi differential pressure

Location at inlet to inner duct (Pig. 1)

Performance: 40 lbs/hr nominal capacity for all nozzles using air

10 micron MVD, nominal designation

Large Sprays:

Type: Hydraulic, hollow-cone pattern
TX-1, designation

Service: For smallest particle size obtainable by this method: extra fine atomization

Fluid: Pressurized water to 460 F

ETF use: 108 nozzles in 12 banks of 9 each at top and bottom of spray section (Fig. 1)

Control by selection of number of banks used together with variable direction of spray, nominally 135° from direction of gas flow

40 psi operating pressure differential

Performance: 900 lbs/hr no&al spray capacity of all nozzles

100 micron MVD nominal particle size rati

-3.2 CALIBRATED UPRIGHT BLOWER (CUB) --

This is an MSA production facility for accurately determining pressure loss of test specimens at known flow rates using ambient air. Permissible operating range includes.800 CFM at 5 in WC to 2600 CFM at 1 in, WC.

. The CUB consists of a vertical duct-with an exhaust fan at the top outlet, a flow orifice.at -mid-height,. and provisions fo installing test specimens-at the lower inlet. Downstream pressure loss through the test specimen is- recorded for given flow rates at atmospheric conditions. Accuracy of flow measurement is checked i place periodically using a Nation-al Bureau of Standards Calibratio Plate.

Separators tested for pressure loss-were operated over the range of approximately 50-200% of manufacturer rated flow valu

3.3 0.3 MICRON DOP PENETRATION TEST FACILITY'

This MSA production facility is regularly used at MSA fo testing HEPA filters. Tests are based on penetration of a calibra stream of DOP particleshaving a meandiameter of 0.3 micron, Hot quenching is used to reach this particle size in an ambient-air test stream of up to 1000 CFM at 1 in. WC. MSA Test Specification No. 1111 is in accord with -the-U. S. Army (Edgewood Arsenal) Instructions Q107 and MIL-STD-282 procedures.

Candidate separators for fine (l-10 micron) service are expected to indicate some 0.3 micron DOP response in the high (>90 penetration range. Reliability of measurements in this high penetration range are questionable without special provisions and proc cures. To set these values in perspective, the following informat is listed, although it has no other bearing on this project.

Normal 0.3 micron DOP penetration. levels measured are <0.03% for HEPA filters and range to 5% for the hospital-service type, and 35 to 55% for high efficiency commercial ventilation service. Standard (household) ventilation filters indicate no measurable 0.3 micron DOP attenuation, giving essentially 100% penetration values.

3.4 0.6 MICRON DOP PENETRATION TEST FACILITY

This MSA test facility is similar in most respects to the 0.3 micron DOP facility except for the "cold" generation which produces the larger, 0.6 micron mean diameter of DOP particles in the test stream. A wider flow range of 800-2600 SCFM at up to 1-5 in. WC pressure differential isavailable. This method is generally used for field-testing high efficiency installations. The larger particle size can be expected to show a significant response when used to screen candidate separators designed for 1-10 micron removal service.

3.5 1.1 MICRON DOP PENETRATION TEST FACILITY

This MSA facility was developed especially-to give a reliable means of indicating the removal efficiency of candidate separator media in the lower portion of the 1-10 micron particle size range of AEC interest.

The 1.1 micron DOP particles are cold-generated similar to the method for 0.6 micron particles. Careful control of generating conditions and resulting particle characterization permitted test operation of this laboratory facility. It-is presently limited to the testing of 4 in. x.4 in. size media pads when reaching normal separator velocity of 400 ± 200 FPM. Media evaluation was discontinued following a few preliminary tests with Teflon, Results are shown in Figure 12 and Figure 13.

Since impactor lower limits in the ETF were 2.5 micron (see Section 6), this 1.1 micron DOP response index would serve to complete the performance curve-measurements between impactor values and the standard 0.6 micron and 0.3 micron DOP measurements. Good correlation between 0.3 micron DOP measurements and arc-generated wet and dry SS-UO_2 particles was reported in ORNL-4524.[10] Similar correlations between DOP values and water particles could serve as a useful index for screening candidate separator materials. Actual performance testing of full-sized separators under simulated water environmental conditions could then be limited to separators fabricated with the more promising media only.

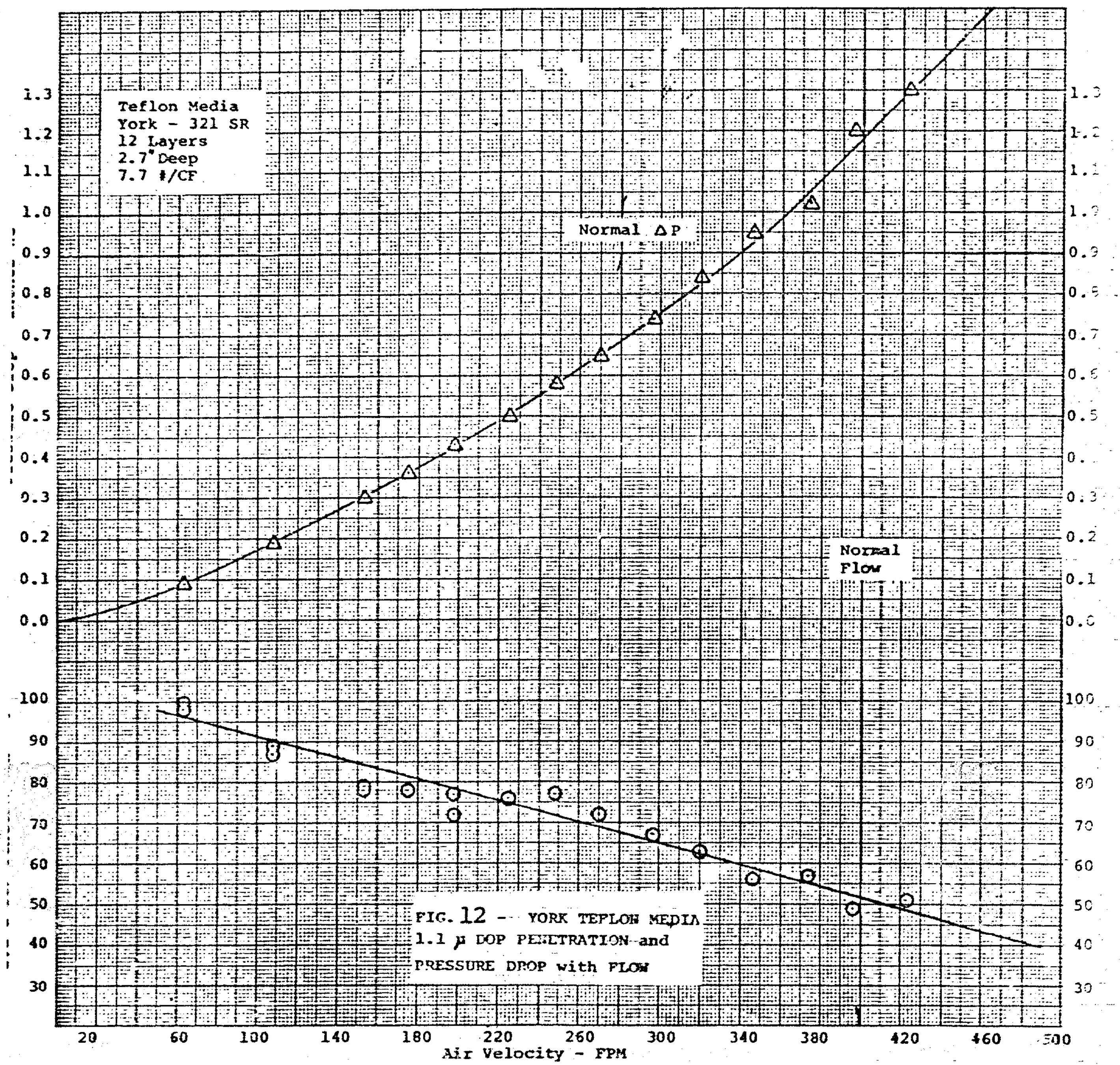


FIG. 12 -- YORK TEFLON MEDIA 1.1 μ DOP PENETRATION and PRESSURE DROP with FLOW

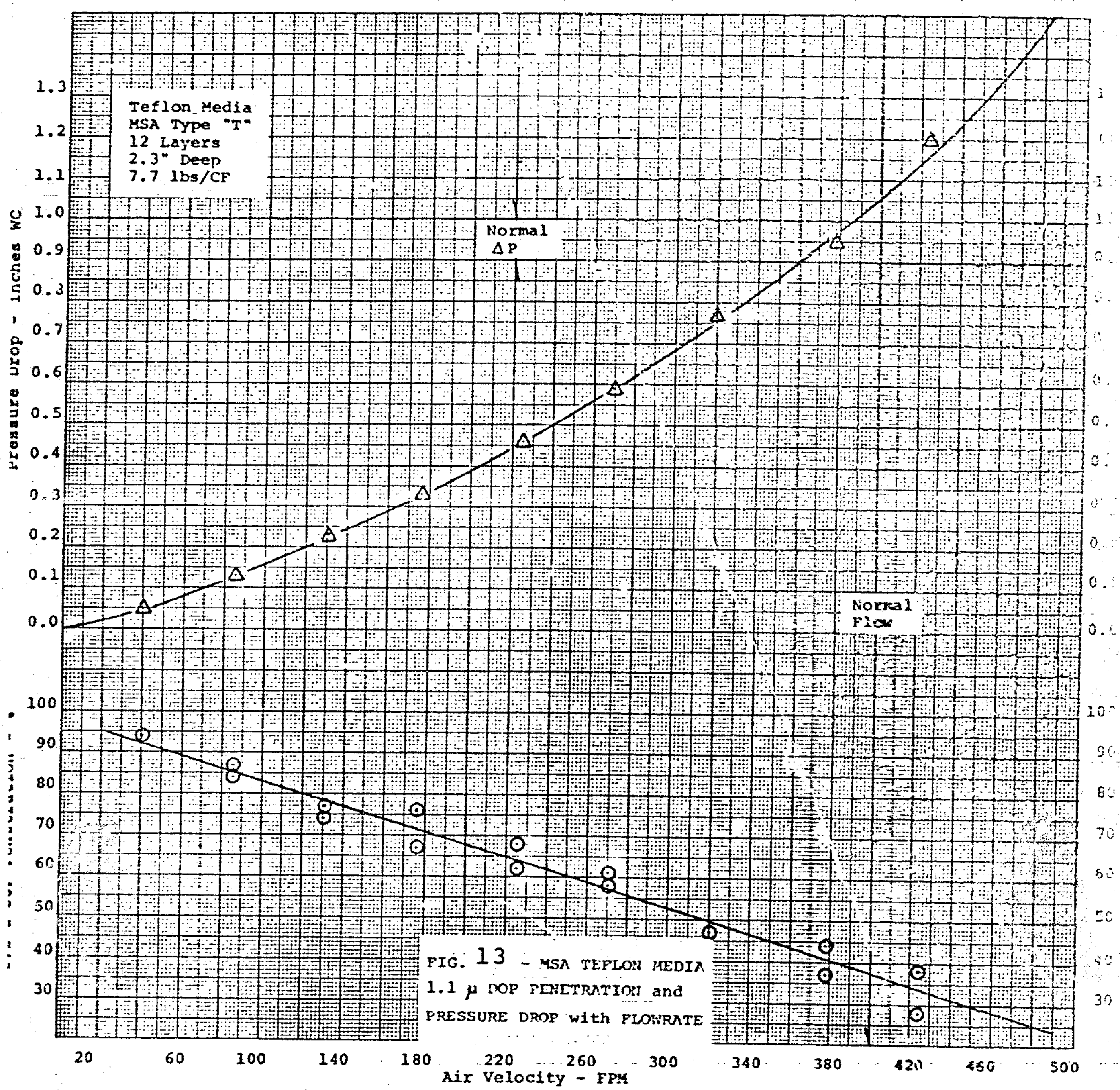


FIG. 13 - MSA TEFLON MEDIA 1.1 μ DOP PENETRATION and PRESSURE DROP with FLOWRATE

4. TEST PLANS ANDPROCEDURES

Reference (2) recommended only two standard separators for testing. However, in the interim between issue of Reference and start of testing, this number increased to the five candidate discussed previously. Additional variations and special separato are available but were rejected for a variety of reasons, such a-s have been discussed in Reference (2).

Test plans concentrated on the prim&y objective of efficiency measurements of separators for removal of entrained moisture, particularly in the l-10 micron particle-size range, Generation and measurement of particles in this range became majo development tasks which were not completely resolved in all aspec as discussed in Sections-5 and 6. Full-sized (24 in. x 24 in, cross-section) separators -varied widely; in depth (2 in, to 24 i in effective face-inlet areas (1.95 to 3.76 sq ft); in rated flow (1140-1800 CFM); and in rated entrainment loadings (<1 to 10 lbs/ 1000 cu ft).

The final test plan included initial measurements at ambient conditions to establish the "normal" descriptive and oper ting functions of each separator in the-"as received" condition. One separator of each type was then tested for actual entrained moisture-removal characteristics in the ETP at ambient conditions. Tests included variations in flow, in entrainment loading and entrainment size. Measurements included: resulting pressure dro of the separator and its downstream monitoring HEPA; visual obser- vation of entrainment; mass measurements of entrainment removed by the separator, by the downstream duct, and by the downstream HEPA; and impaetor sampling to identify particle size fractions. The final "normal" performance properties of each separator and t HEPA filter used with it were rechecked following ambient entrain ment testing. Repeat testing with a duplicate separator or varia of test conditions were performed when indicated by data obtained. only separators indicating good entrainment removal efficiency in the l-10 micron particle size range at ambient conditions were selected for -additional testing at PWR incident conditions of ele- vated temperature and pressure, and for extended performance properties and limits. An outline of the test procedures is as follows:

4 .1 DETERMINATION OF 'NORM"

All separators of each type were examined as follows:

4.1.1 Dimensions; weight

4.1.2 Description of separator, its appearance, photographs

4.1.3 Flow - differential pressure measurements over nominal range of 62.5 - 100-125% of rated flow, on CUB

4.1.4 0.3 micron DOP - differential pressure at 1000 CFM

4.1.5 0.6 micron DOP - differential pressure 62.5 - 100-125% of rated flow

4.1.6 1.1 micron DOP, on 4 in. x 4 in. media only when available

4.2 ENTRAINMENT TEST, AMBIENT, CLEAN ETF

One separator of each type was tested in the following sequence unless test results indicated further testing was not warranted. Limiting XEPA differential-pressure to 4 in. WC was the initial criterion for continuation.

4.2.1 Efficiency of at least 99% at rated flow and 100 micron loading:

By mass balance of separated entrainment.
By impactor of any 1-10 micron fraction.
By observation of water particles passing through the separator.

4.2.2 Repeat, using 100 + 10 micron MVD loading

4.2.3 Repeat, using only 10 micron MVD loading

4.2.4 Efficiency at 10 micron loading with 62.5% and 125% of rated flow when good performance is indicated

4.2.5 Duration of tests to be 4-16 hours as required to reflect steady-state operating performance

4.2.6 Remove and weigh HEPA immediately following test

4.2.7 Recheck "norm" of separator (4.1) and HEPA after drying

4.2.8 Repeat with duplicate separator to resolve any doubtful areas

4.3 ENTRAINMENT TEST, INCIDENT, CLEAN ETF

Separator types with the highest performance in the previous tests (4.1, 4.2) were initially selected for further testing at PWR incident conditions at up to 4 in. WC differential

4.3.1 Recheck ambient differential pressure at rated flow. Dry, with 100 micron entrainment in the ETP

4.3.2 Reach incident quickly at rated conditions, using 100 micron loading and indirect steam heating. Start with MSA Type G in order to debug the ETF controls following revisions.

Prior modification runs T-12 through T-16, using Type G separator, indicate maximum heat-up rate feasible and desirable,

4.3.3 Level out at high loading of 100 micron MVD. Get data profile, including efficiency measurements.

4.3.4 Reduce 100 micron MVD loading; obtain steady-state data:

4.3.5 Check relative humidity effect of TX-1 sprays in annulus.

4.3.6 Operate without sprays; get data profile.

4.3.7 Operate cooler to generate entrainment. Get data profile and observations.

4.3.8 Operate with 1-10 micron maximum loading using steam to atomize system water filtered to 1-a nozzles.

4.3.9 Duration of test to be 16-24 boors total at incident-exposure conditions, or as required to reflect steady-state operating performance and reliability,

4.3.10 Recheck "norm" of both separator (4.1) and HEPA filter following incident test,

4.3.11 Recheck incident test with duplicate separator to clarify any doubtful areas. Modify test conditions as required to give answers needed.

5. ENTRAINMENT GENERATION DETAIL

Existing technology and hardware for generating finely divided aerosols were studied for methods of obtaining bulk quantities of 1-10 micron entrainment at ambient and at incident conditions for full-sized separator test evaluation work in the ETF. In general, available hardware (ultrasonics, spinning disks, etc.) was found to be limited to small capacities at ambient conditions, as previously reported.[1] Spray nozzles offered the only readily available means of generating entrainment approaching that currently predicted for PWR contaminant incident conditions (Table 1). The spray nozzles used for this evaluation work are shown in Figure 1, with descriptive tabulation in Section 3.1.2 and general performance -discussed in this section,

Particles resuiting from sprays under actual conditions vary widely in size and distribution and, thus, so does the volume or mass of liquid, Some methods for giving a measure of this droplet-size characterization are defined as follows:-

SMD - Sauter Mean Diameter is a means of expressing the fineness of a spray in terms of tie surface area produced by the spray. It is reached by obtaining -a summation of the surface areas of every drop produced by a given spray, together with a summation of the total volume of all these drops. Then the diameter of a drop having the same volume-to-surface ratio gives the SMD of this spray.

MND - Mean Numerical Diameter is a means of expressing particle size in terms of the number of particle& in the spray. This means that 50% of the particles presented by count or number are smaller, and 50% are larger than the given (MND) particle size,

MVD - Median Volume Diameter is a means of expressing particle size in terms of the volume of liquid sprayed,. The MVD size of a spray is that value where 50% of the total volume (or mass) of the liquid sprayed is made up of droplets having diameters larger or smaller than this median value,

Selection of the basis of characterizing sprays depends upon the application understudy, Spraying Systems Company[11] is presently characterizing spray nozzles for commercial purposes based on MVD measurements. An electronic Stroboscopic-Television Sensor and Tabulator System is used to obtain reliable measurements down to 30 micron with sensitivity possible down to 20 micron. Since results were readily available for most of their nozzles and since HEPA protection depends upon volumetric or mass efficiency of separators, the MVD basis of characterization was selected for purposes of this report. For efficiency versus particle size, th measurement of particles in each limited range is still required.

Performance estimated by Spraying Systems for the 1-A and TX-1 nozzles used in this evaluation, together with nozzles cc for two PWR separator tests[6,8], are presented in Table 2. Figure 14 illustrates both the wide MVD variation between nozzles and th variation with operating pressure from each nozzle. Figure 15 illustrates the performance range measured by Spraying Systems for standard nozzles. Figure 16 gives the estimated performance rang: of the TX-l and 1-A nozzles. TX-1 values are probably rather. accurate since measurements were made-on similarly sized nozzles. The 1-A values below 20-30 micron are below Spraying Systems measuring capabilities and may diverge appreciably.

Typical particle sizes and distribution for small hydraulic and pneumatic nozzles given in Reference 17 are presente in Tables 3A and 3B. These further indicate what can be expected from the TX-1 and 1-A nozzles used: the smallest available. Por the hydraulic nozzles, Table 3A shows a large number of particles are present in the 10 micron size, although their volume percent will be small. At a constant inlet pressure, the number of small (10 micron) particles increases with decreasing orifice size: 100 measured with the 0.086 orifice at100 psi increases to 800 with the 0.063 orifice. The 0.020 orifice in the TX-1 nozzle can be expected to have an even larger number of 10 micron droplets, From the data in Table 3A, MSA calculated a 22 micron MND and a 335 micron MVD particle designation for the 0.063 orifice at 50 ps These can be compared to the TX-1 nozzle for which the manufacture measured 100 micron MVD.

From analogy, the MND of the TX-1 nozzle should be much smaller than 22 micron. Pneumatic nozzle data in Table 3B indicat that a large number of droplets are generated in the 2-10 micron size range. Calculated values for median size designations from the tabulated values give 4.5 micron MND and 15 micron MVD. Comparison to the 1-A nozzle, selected for finest obtainable atomization, indicates considerably lower distribution values (~3 micron MND, ~10 micron MVD nominal). Impactor measurements of 7-8 micro MVD (Section 6) bear this out and indicate that the Spraying Syste estimate (Table 2 and Figure 14) of 25 micron MVD may be high.

The number of nozzles selected for the ETF tests was based on reaching measurable concentrations of particles in the 1-10 micron range using Type 1-A nozzles to Peach an output of 40 lbs/hr of 10 micron MVD, using air for ambient tests and steam at incident conditions. Bench tests of one Type 1-A nozzle gave 0.13 lbs/hr using 30 psi steam versus 3.1 lbs/hr using air (Sectio 6). This indicated a reduction on the order of 25:1 for steam -- considerably lower than anticipated by Spraying Systems (Table 2).

TABLE 2 . SPRAY NOZZLE CAPACITIES and PARTICLE SIZES using 70F WATER

From SPRAYING SYSTEMS CO.,[22] Published Data and Communications to MSA

:le)er /pe	Operating Pressure psi	Particle Size, Microns (μ) 2 Vol % Below	50 Vol % (MVD)	2 Vol % Above	Liquid Rate gal/hr	lb/hr	Air Rate* SCFM	Remark,
)	20		2420		84	740		Connecticut-Yankee Reactor Tests[5]
:aulic	40	6.50	2040	4020	120	1000		
	100	425	1220	2800	186	1550		
.3	20	260	700	1300,	2.52	21.0		Indian Point-2 Reactor Tests[3]
:aulic	40	218	580	1020	3.60	30.0		
	100	124	300	560	5.70	47.5		
			**					
l	30	56	120	200	0.83	7.4		Used For This Evaluation to Make up Bulk Loading
:aulic	40	46	100	163	1.0	0.3		
	300	26	60	108	1.5	12.5		
			• ⊠		@ 8" Siphon Height			
	5	10	25	46	0.08	0.67		Used For This Evaluation For 1-10 μ Portion
	10	15	36	63	0.18	1.50	0.40	
ımatic	20	17	40	72	0.31	2.58	0.59	
ıizing	40	19	44	80	0.38	3.17	0.35	

*Steam Rate estimated @ 2 1/4 lb/hr-SCFM Air Rate tabulated, with somewhat reduced Liquid Rates - Keller, Telecon - 1970

**Estimated by Haruch, 8/27/69

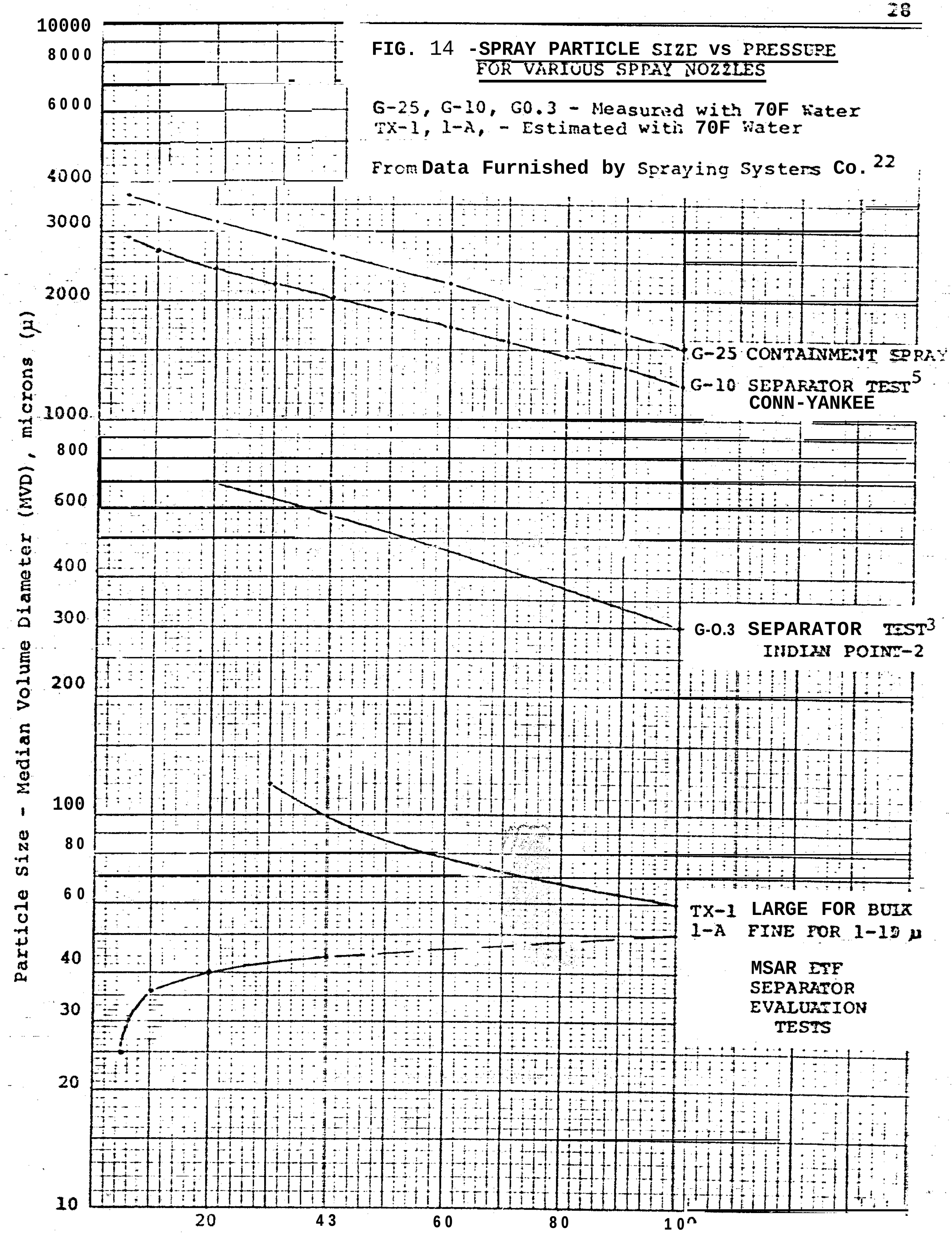
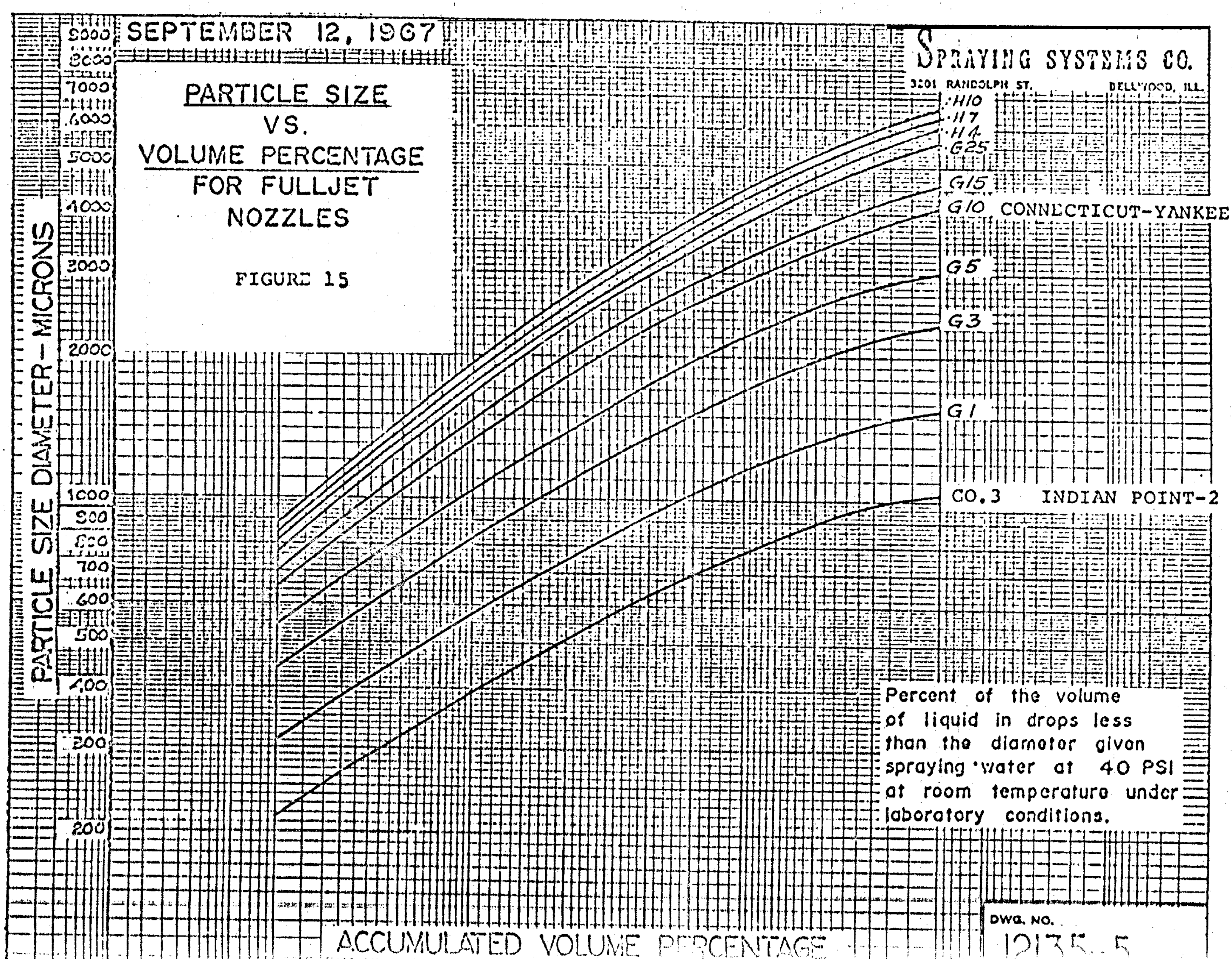


FIG. 14 -SPRAY PARTICLE SIZE VS PRESSURE FOR VARIOUS SPRAY NOZZLES
G-25, G-10, G0.3 - Measured with 70F Water
TX-1, 1-A, - Estimated with 70F Water
From Data Furnished by Spraying Systems Co.[22]
10000
8000
6000
4000
3000
2000
1000
800
600
400
300
200
100
80
60
40
30
20
10
Particle Size - Median Volume Diameter (MVD), microns (μ)
20
43
60
80
100
G-25 CONTAINMENT SPRAY
G-10 SEPARATOR TEST[5]
CONN-YANKEE
G-0.3 SEPARATOR TEST[3]
INDIAN POINT-2
TX-1 LARGE FOR BULK
1-A FINE FOR 1-10 μ
MSAR ETF
SEPARATOR
EVALUATION
TESTS


SEPTEMBER 12, 1967
PARTICLE SIZE
VS.
VOLUME PERCENTAGE
FOR FULLJET
NOZZLES
FIGURE 15
SPRAYING SYSTEMS CO.
3201 RANDOLPH ST.
BELLWOOD, ILL.
H10
H7
H4
G25
G15
G10 CONNECTICUT-YANKEE
G5
G3
G1
CO.3 INDIAN POINT-2
Percent of the volume of liquid in drops less than the diameter given spraying water at 40 PSI at room temperature under laboratory conditions.
PARTICLE SIZE DIAMETER – MICRONS
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
ACCUMULATED VOLUME PERCENTAGE
DWG. NO.

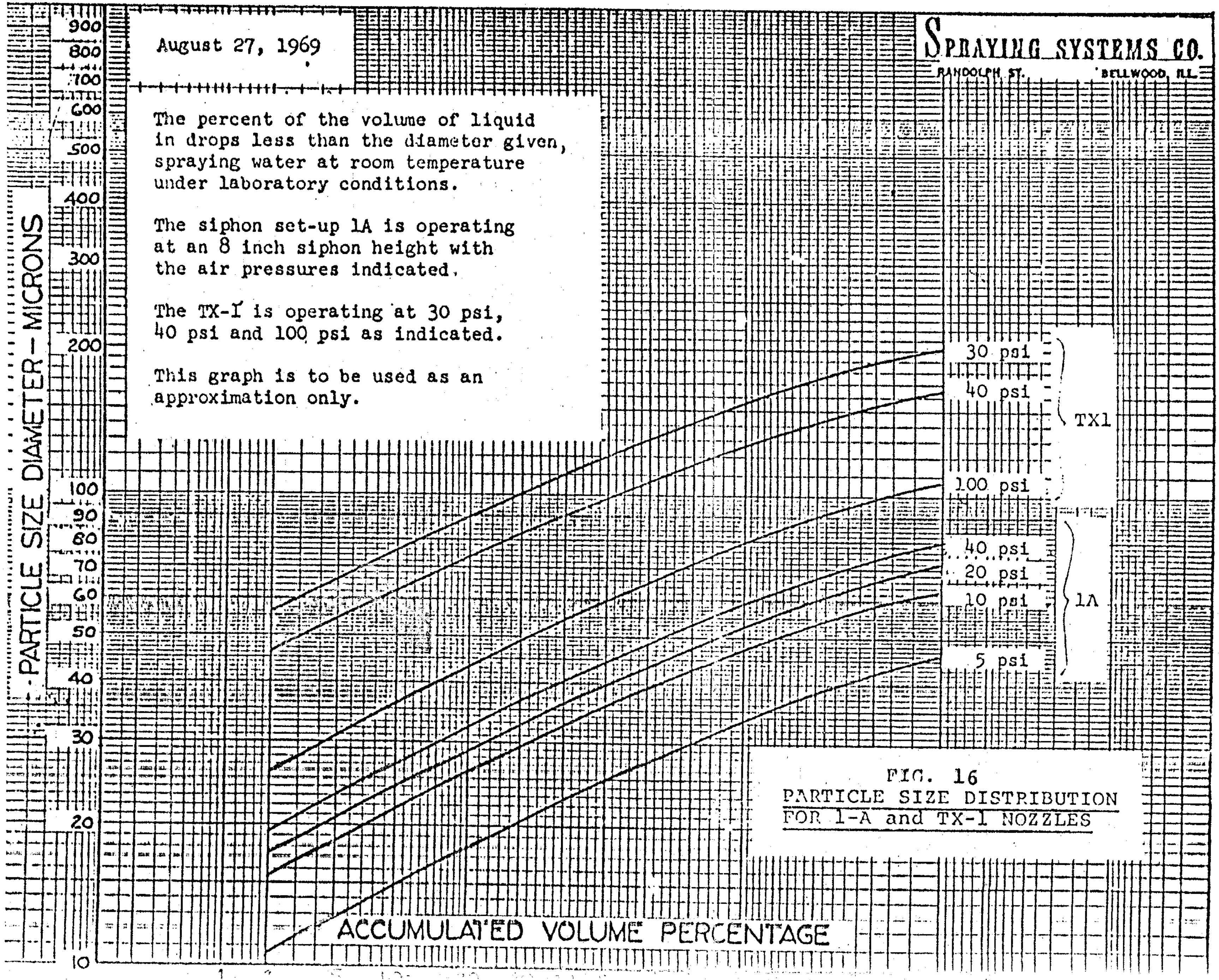


FIG. 16
PARTICLE SIZE DISTRIBUTION
FOR 1-A and TX-1 NOZZLES

TABLE 3 - DROP SIZE DISTRIBUTION OF SMALL HYDRAULIC AND PNEUMATIC NOZZLES WITH ANALOGY TO TX-1 AND 1-A NOZZLES

Table 3A from Reference 17

Table 18-18. Drop-size Distributions Produced by Three Hollow-cone Nozzles of the Same Design

Nominal drop diam., μ	Number of drops in each size group: 0.063-in. orifice diam., 50 lb./sq. in.	0.063-in. orifice diam., 100 lb./sq. in.	0.063-in. orifice diam., 200 lb./sq. in.	0.086-in. orifice diam., 100 lb./sq. in.	0.086-in. orifice diam., 200 lb./sq. in.	0.128-in. orifice diam., 200 lb./sq. in.
10	375	800	1700	100	300	100
25	200	280	580	60	150	50
50	160	180	260	41	100	45
100	50	60	70	26	34	27
150	27	31	35	14	18	15
200	19	23	27	9	12	11
300	8	9	11	5	8	6
400	2	4	4	4	7	3
500	1	1	....	2	1	2
600	1	...	....	1		1

NOTE: 1 μ = 10^{-4} cm. = 0.0000394 in. The nominal diameter is the mid-diameter of a drop group which includes a finite range of sizes. The "25" group includes drops from 17.5 to 37.5 μ, the "50" group contains drops from 37.5 to 75 μ, etc. The number of drops has been adjusted in each case so that the total amount of fluid sprayed is the same for each size distribution.

Comparison of mean diameter values:

From Table 3A above. For 0.063 diameter orifice nozzle operated at 50 psi	For TX-1 nozzle having 0.020 diameter orifice operated at 40 psi.
22 μ MND	<2 *2* μ MND, by analogy
335 μ MVD, calc.	100 μ MVD, measured by Spraying Systems Co

Table 3B from Reference 17

Table 18-19. Drop-size Distribution of a Small Atomizing Nozzle

Drop diam., μ	Number of drops	Drop diam., μ	Number of drops
2	393,820	35	1,730
5	340,030	40	1,060
10	165,950	45	650
15	40,280	50	430
20	11,650	60	350
25	4,970	70	220
30	2,160		

NOTE: The fluid pressure and the gas pressure were each 15 lb./sq. in. The total quantity of fluid represented by this size distribution is the same as that in Table 18-21, so that the numbers of drops are directly comparable.

Comparison of mean diameter values:

For tabulated nozzle	*For* 1-A nozzle at 5-10 psi, siphon feed
4.5 MND, calc.	<5 μ MND, by analogy

It is assumed that these bench test results reflected some condensation of steam into the siphon feed. ETF results with steam verified a-clearly visible, but barely measurable, concentration of fine particles.

6. FINE PARTICLE SIZE MEASUREMENTS

Prior to undertaking the task of measuring separator efficiency, an extensive state-of-the-art search was conducted, as previously reported[1]. Knowledgeable personnel and leading instrument manufacturers were contacted to provide help in selection of hardware and methodology. The results of this survey --revealed:

1. The state-of-the-art was'extremely poorly defined.

2. No off-the-shelf hardware or methodology -*were* available.

3. The impaction principle was the most realistic approach.

There remained the problems of mating-the impactor design to the environmental conditions and the development of a method for characterizing (fingerprinting) the droplets in situ.

The principle of an impaction device has been extensively employed[12,13] Basically, an impactor consists of a series of jets and sampling slides. The jets are progressively finer so that the velocity of a sample stream pulled through the unit increases at each jet. The placement of the sample slide behind each jet causes the sample stream to make an abrupt turn. Large particles are carried by the air or sample stream impact by inertia-onto the sample slide; small particles are carried to the next jet where, because of increased velocity, the efficiency of impaction increases, The net result is a size grading at each sampling slide, such as is shown in Figure 17. The size range of particles which can be collected depends upon the specific impactor design with the *lowest* level of collection being somewhat less than 1 micron in diameter.-

6.1 SELECTION OF IMPACTOR

Response of fine liquid droplets to the process of impaction was largely uncertain. Evaporation, condensation, coalescence and fragmentation are all processes which can occur with liquid droplets, A study of water-droplet size changes in a Lundgren-type impactor was performed for MSA by W. L. Torgeson of the Environmental Research Corporation.[14] Based on the assumption that the air-water vapor mixture was fully saturated at the inlet to the first nozzle and the maintenance of isothermal conditions, the conclusion reached was that, with proper impactor design, particle evaporation or condensation are insignificant for 1 micron particles or larger.

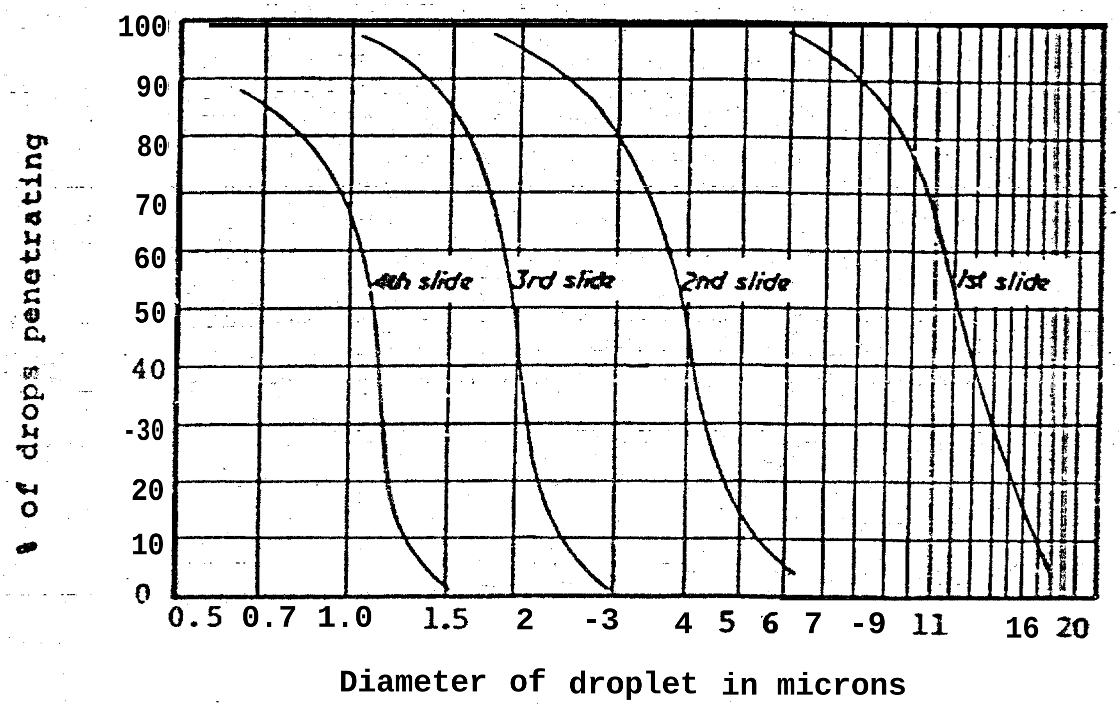


FIG. 17 - EFFICIENCY OF THE-FOUR STAGES OF THE CASCADE IMPACTOR (15)

Attention was first drawn to the Lundgren Impactor because it employed rotating drums as collecting surfaces; hence, high particle densities could be sampled since pile-up of droplets was minimized. ERC was subsequently commissioned to fabricate two units for use at incident conditions. Unfortunately, the first models delivered were found to be inoperative at 212 F. Major problem areas were the drive-train assembly and the drum shafts which loosened-at increased temperatures. The defective areas were subsequently repaired by the manufacturer. Meanwhile much of the laboratory development of procedures for sampling and interpretationof results was performed using a Cassella Impactor which employs stationary collection plates;. Eventually it was found that the methodology which evolved from the Cassella studies could not be successfully applied to the Lundgren.

Although residual mechanical problems did persist, presumably the major difficulty with the Lundgren impactor was in developing the proper spacing between the drum surface and the slit opening in the third and fourth stages. Placement of the support media or particle-collection media within the original. critical spacing caused erratic results. An empirical approach was tried in which the drums were turned down about 0.002 in, and then shimmed to the optimum spacing by successive thin layers of paint (Egyptian lacquer).- Correct spacing was to be determined by the closeness of approach to the listed cut-off values. Although this approach was viewed as promising, the program could not be delayed for additional development work. The degree of "readiness' of this instrument at the-start of the separator-test schedule is best illustrated in Table 4, Cut-off values for each stage as determined experimentally at 212 F are compared with the original design goals. No collection of droplets was ever found on the fourth stage.

TABLE -4 - DROPLET SIZE COLLECTIOl.3 FOR THE FOUR STAGES OF THE LUNDGREN IMPACTOR

Stage	Cut-off Values (μ dia)* Designed Value	Found
1	27	30
2	8	17
3	2.7	5-10
4	0.8	

* 50% collection efficiency

for comparison, the critical design parameters of tie Cassella and the Lundgren Impactor are shown in Table 5.

TABLE 5 - DESIGN FACTORS: LUNDGREN vs. CASSELLA IMPACTORS

Stage	'Stage Velocity, ft/sec	cut Points, micron*
	CASSELLA IMPACTOR (0.62 CPM)	
1	7 . 6 7	21.0
2	45.5.	5.0
3	90.3	1.9
4	250.8	0.67
	LUNDGREN IMPACTOR (1 CFM)	
1	5.0	27.
2	15.3	8
3	4 5 . 0 ,	2.7
4	130	0.8

* 50% collection efficiency

In summary, it was determined that the Lundgren instrume could not completely meet its design objective without farther modification (i.e., droplets less than 5 micron in diameter could not be detected) and it was found that the Cassella instrument could be adapted to the program. In the interest of expediting th work, a decision was made to use the Cassella instrument,

A mathematical study was performed to evaluate the possible limitation of the Cassella Impactor using the guidelines set forth by Torgeson. Details of the study are included in Section 6.5. In brief, the study disclosed that particles would evaporate somewhat by passage through the impactor and that this effect would be about the same at both incident and ambient conditions. In general, the finer particles would be more vulnerable. Calculations showed that a 2.7 micron particle would eventually measure 2.5 micron at the time of-impaction on the third stage, It was also predicted that all particles not removed on the third stag would evaporate rather than be collected at the fourth stage. This has been verified since no collection was ever observed on the fourth stage of the Cassella Impactor. The Cassella Impactor was, however, considered acceptable for the measurement of fine (2.5 - 10 micron) water droplets in the separator efficiency test program. Using the 2.5 micron lower limit was not considered detrimental to the program since data from the spray manufacturer indicated that the volume of water in the particles below 2.5 micron is very low.

6.2 LABORATORY TEST SYSTEMS

Two basic laboratory test systems were constructed primarily to develop fine particle generation and measurement techniques and to supply engineering support data. An ambient test loop featured an ultrasonic generator (1 to 10 micros) and was housed in a constant, low-temperature enclosure for operation at atmospheric pressure. It is illustrated by Figure 18 and further discussed in this section. The second system consisted of a 6 in. diameter glass tunnel which was operated at elevated temperatures using steam with generators or nozzles of interest. The glass tunnel system also permitted study of sampling techniques at elevated temperatures and is illustrated by Figure 19.

In the ambient test system, as illustrated in Figure 18, a blower was used to recirculate humidified air through a loop of 3.5 in. diameter plexiglass tubing. Air flow from the blower was cooled by a small condenser and then passed through a miniature separator to minimize the continuous build-up of fine particles that would be present in the return air. A hygrometer was installed across a damper and the intake to the blower. Further downstream from the separator, a portion of the total stream (0.5 CFM) was used to continuously transport the cloud of newly formed particles present in the generator cup to the working loop. Heat generated in the particle generator was removed by the addition of a cooling coil.

Provisions were made to test small entrainment separator elements by using two sample probes, as shown in. Figure 18, Samples were withdrawn through solenoid valves using externally-controlled switches. An auxiliary source of fine particles was fed to the upstream side of the blower to enhance the humidification of the air stream. In general, all motors, blowers, power supplies, etc., which could yield heat were mounted either in separate compartments or external to the test system. The working loop described above was housed in a constant-temperature box and the air temperature in the box containing the test loop was controlled to within 0.5 F.

Experience with this ambient test system clearly indicated the difficulty likely to be encountered in striving to approach 100% relative humidity conditions. It was extremely difficult to hold the relative humidity of the test stream at 98% or higher as measured by a wet bulb-dry bulb hygrometer. At this level of saturation, the water-vapor content had either a tendency to creep toward saturation (as evidenced by condensation on all surfaces, including the dry bulb), or to fall to a lower and more stable level. Generally, tests at 98% relative humidity or above had to be cons-ted during the time period d-zing which the relative humidity was approaching 100%.

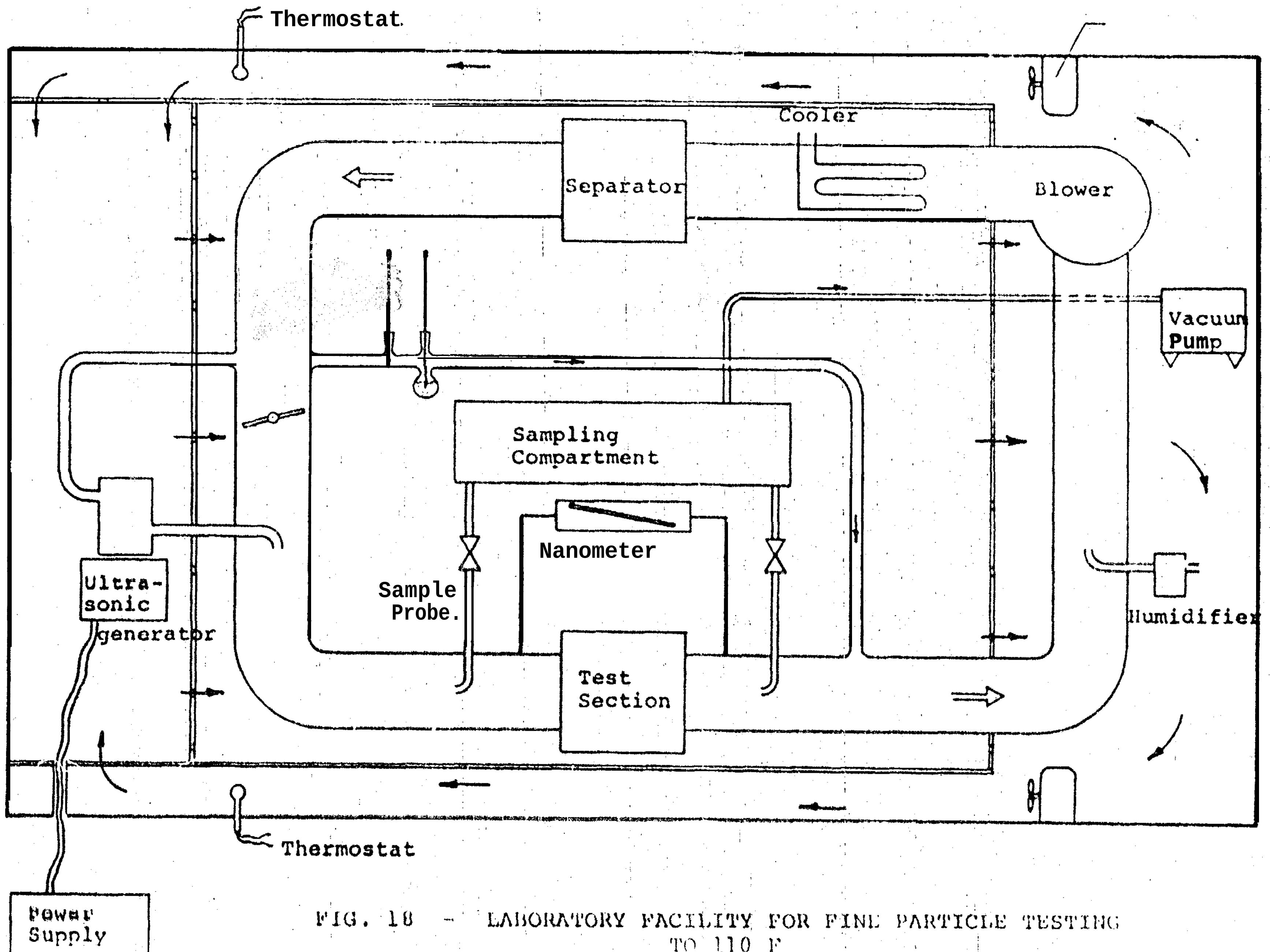


FIG. 18 - LABORATORY FACILITY FOR FINE PARTICLE TESTING TO 110 F

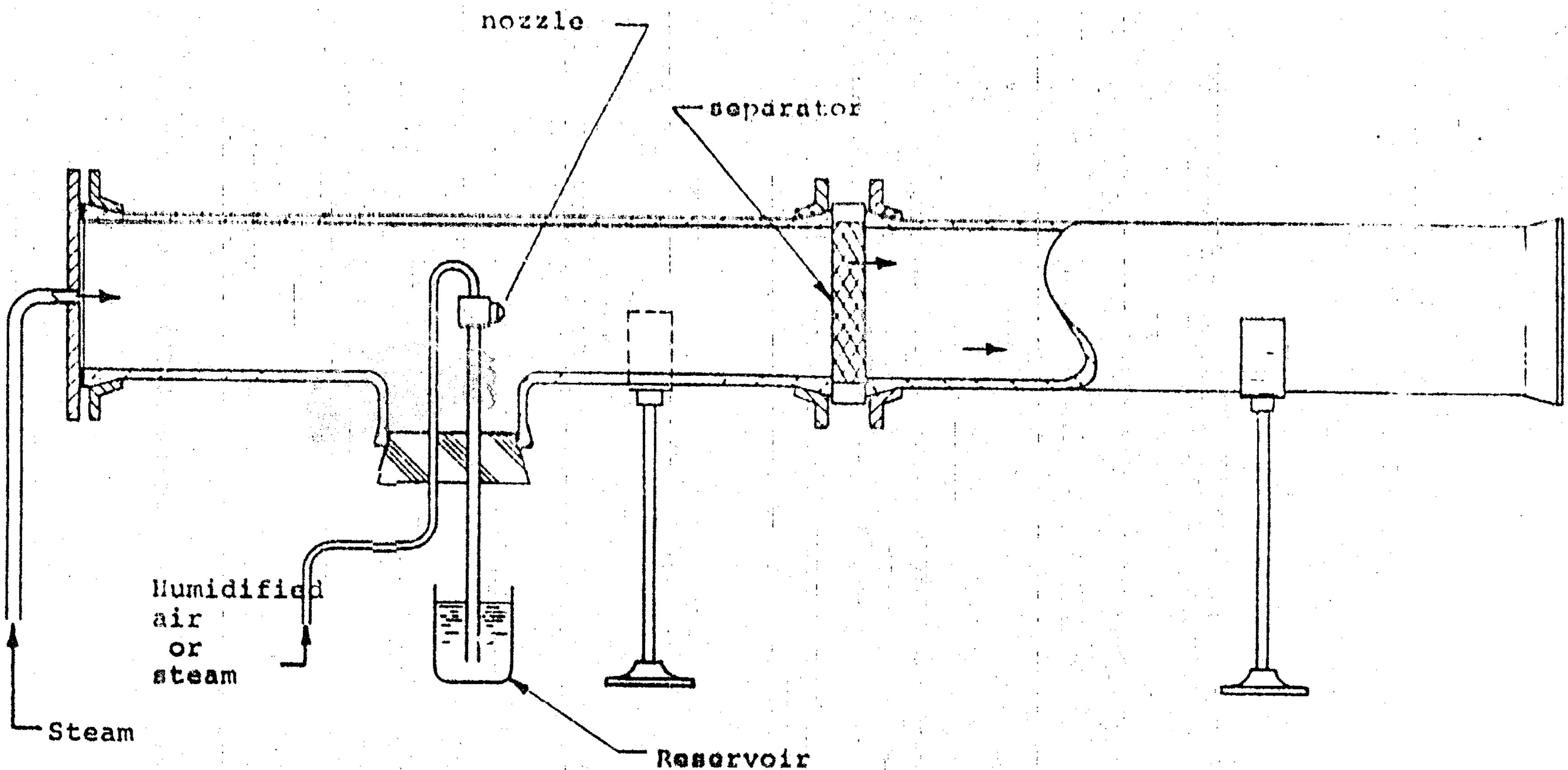


FIG. 19 - Lab Facility for Fine Particles Testing to 212 F

The relatively simple glass-tunnel test facility, shown in Figure 19, served a threefold purpose: first, to test the impactor at elevated temperature; second, to test nozzles for small particle generation: and third, to test the efficiency of various media in removing small particles. The results of the impactor tests are discussed in Section 6.3. Primary consideration was given to Spray Systems 1A nozzles because a survey of manufacturers indicated that this was the only nozzle worthy of testing.

6.3 DEVELOPMENT OF COLLECTION SURFACE

Considerable laboratory effort was focused on the selection of the coating surface which would record the impact of the moisture droplet. The three coating techniques examined were the use of magnesium oxide, a soft-oil-grease coating, and a water-soluble stain. Each of these coatings was examined on glass slides in the Cassella Impactor. The glass collection slides were about 25 mm in diameter and 0.19 to 0.25 mm thick (Corning No. 2915). Initial studies were conducted using the glass tunnel at 210 to 212 F as a reasonable approach to the elevated temperatures of incident conditions; The test unit consisted of a single 1A nozzle activated by a stream of humidified air. The spray was carried by a flow of steam through a loosely pecked separator punctured with several small holes. The intent here was to reduce the total particle population originated at the nozzle to values acceptable by the impactor. Sampling was accomplished at the exit of the tunnel using the impactor preheated to stream conditions (212 $\pm$ 2 F). The findings with each of the coating techniques are described below.

6.3.1 MgO Collection Surface

Coatings of MgO are applied to a surface by merely introducing the cool receptive surface into the plume of MgO particles generated by burning magnesium metal. Depth of coating can be controlled by the exposure time and location in the plume. The result of the coating is a continuous layer of the fine particles of MgO (0.3 to 0.5 micron in diameter). Upon impact, the droplet disrupts the coating and leaves a crater which can be related to the original droplet particle size. It was found that at ~212 F the coating yielded very poorly defined craters at particle sizes below 5 micron. This method was subsequently abandcced.

6.3.2 Grease-Oil Collection Surface

The intent of the use of this type of coating is to provide for a relatively soft impact surface which, similar to MgO coatings, would leave a crater. The coatings were prepared using silicone stopcock grease dissolved in silicon oil (DC200). Experience with various formulations yielded coatings either too hard to cushion the impact or too "soft" at the elevated temperatures to retain the impact crater. This technique may yet be feasible and it was rejected here only due to the failure to develop a suitable formulation within the allotted time.

6.3.3 Soluble Stain Collection Surface

Unlike the-previous techniques which leave craters, a moisture droplet contacting a stained surface leaves a washed out or bleached area of impact. The dye selected for this effort was Niagara *Sky* Blue 6B obtained from Fisher Scientific (Cat. No. NA489). Although the material can be used as received, an improved coating film results from recrystallizing the stock material from a water-alcohol-solution. The glass slide must be spotlessly clean-to allow a continuous film to form. Imprints formed by the droplet were found to be -exceptionally clear and well defined. Characteristic imprints are shown enlarged in Figure 20. Each imprint consists of an inner area in which the stain has been completely removed and an outer periphery where excess dye has eventually piled up. Of the three techniques examined, the use of the soluble -stain was clearly superior.

The two major difficulties associated with the use of the stain method were its tendency-to wash out as a result of condensation and the uncertain relationship between the print diameter and the particle diameter (spread factor). Subsequent studies with steam showed that condensation could be eliminated by maintaining the impactor initially at 5 F above the sample-stream temperature and by purging-the impactor.with dry air both prior to and at the completion of the sampling period.

6.3.4 Estimating the Spread Factor on a Soluble Stain Collection Surface

The resulting imprint of the stain in the area of impact is undoubtedly a combination of physical and chemical forces. Since no standard-size particles in the 1 to 10 micron *range are* available, an estimate of the spread factor was accomplished in an indirect *manner.* Presented in Figure 17 are the collection efficiencies for a unit-density particle as determined by May[15] using his own impactor design. Table 6 permits a comparison between the design feature of the May impactor and that of the Cassella, It was assumed that the two different impactors were sufficiently. similar so-that the second-stage efficiency curves would also hold true for the Cassella. Figure 21 shows the second-stage efficiency curves obtained using the stain method in the Cassella. This work was done in the ambient test loop using the ultrasonic generator as a source of 1 to 10 micron particles. The relative humidity was in excess of 98% as measured by the wet-dry bulb hygrometer. Two curves are shown: the first represents the data obtained by measuring the outer periphery of the droplet and is compared to measurements made using the inner or bleached area.

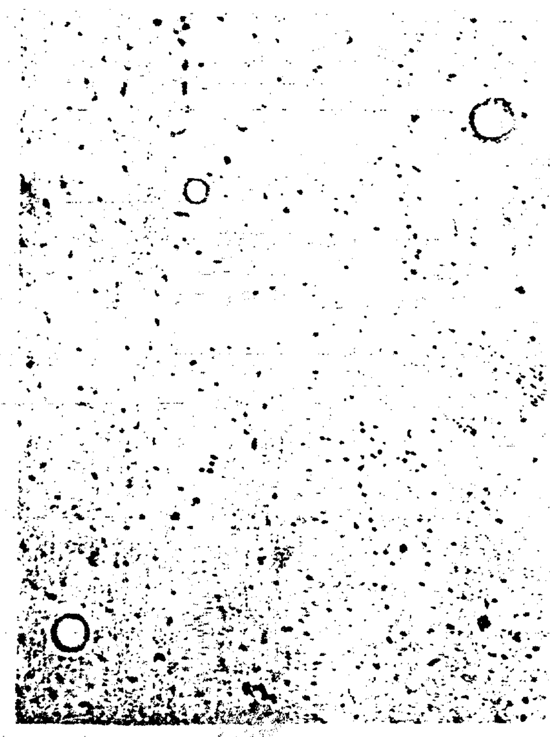


FIG. 20 - Fine Water Particle Imprints on Soluble Stain Coated Surface

TABLE6 – CASSELLA vs MAY, IMPACTOR COMPARISON

Stage No.	Jet Length (mm)	3et Width (mm)	Stage Velocity (m/sec)	Minimum Size Efficiently Removed	
				Calculated (u)	Experimental (u)
			MAY (1945) IMPACTOR		
1	19.0	6.5	2.2	21.0	19.0
2	14.0	2.0	10.2	5.1	6.5
3	14.0	1.0	20.4	2.6	3.0
4	14.0	0.6	30.4	1.5	1.5
			MSA-CASSELLA IMPACTOR		
1	19.0	6.5	2.36	21.0	22.0
2	14.0	2.0	11.0	5.0	7.0
3	14.0	0.75	27.8	1.9	2.3
4	14.0	0.27	77.2	0.67	0.7

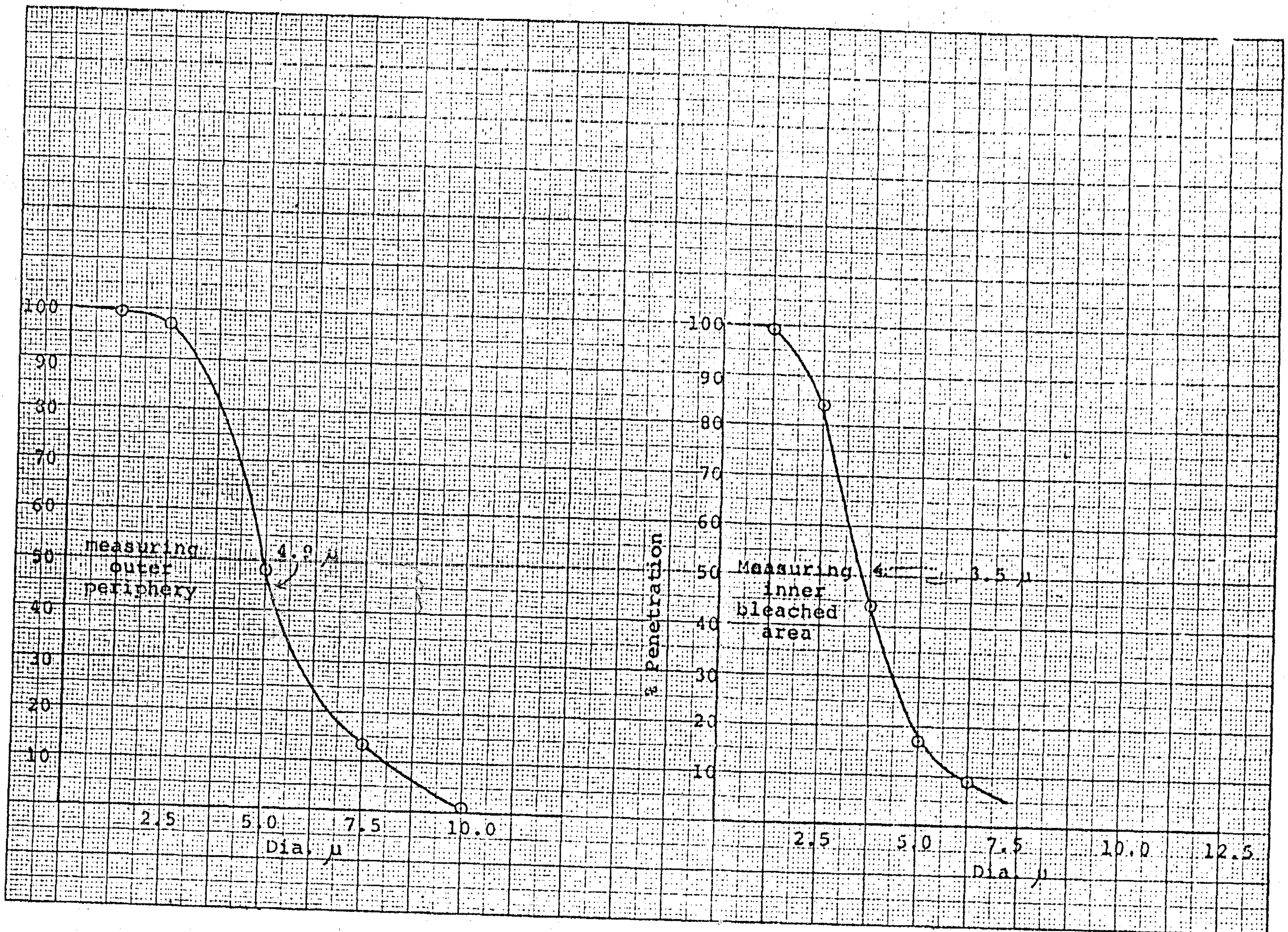


FIG. 21 - CASSELLA SECOND STAGE EFFICIENCY- OUTSIDE vs INSIDE OF IMPRINTS

The 50% cut-off value, found for the Cassella second stage; was 4.9 or 3.5 micron. From Figure 17, May[15] reports a value of 3.9 micron. It was decided that the outer or maximum spread of the stain would be measured (4.9 micron) and a correction factor of 0.8 applied (4.9 x 0.8 = 3.9 micron). It was assumed that this spread factor was reasonably constant in the 1 to 10 micron range. Spot checks indicated that no major change was prevalent at a temperature of 212 F.

6.4 SIZING -AND COUNTING SLIDE PARTICLES

Particle-size measurements were performed microscopically -using a precalibrated eyepiece; Imprints found on the second and,. -especially, the third stage were found grouped in a narrow band. Where a large number of- counts were to be made, measured sections of- this band were-counted, averaged-and then multiplied by the total length of the collection band. Particles were sized by direct measurement and grouped into-the following sizes: 2.5, 4.0, 5.6, 7.2, 8.8 and-lo.0 micron. The smallest particle size located on the third-slide was about 1.6 micron after- correcting for the spread factor. Particles of this-size were grouped as 2.5.micron to adjust for the shrinkage phenomenon. Particles above-' this range were grouped in the above-listed categories without allowances for shrinkage, since the analyses showed this to be negligib-le for large 'droplets. (See Section 6.5.)

6.5 ANALYSIS OF DROPLET SIZE CHANGE

The analysis presented by Torgenson[14] was applied to the MSA-Cassella Impactor. Table 7 gives the droplet diameters for each stage, for a flow rate of 17.5 liters/minute (actual)-of saturated air at 100 F and 1 atmosphere. Table 8 gives the same data for 17.5 liters/minute at 271 F and 47 psig. The size changes were moderate for the early stages but large for the last stage. The largest particles are not greatly affected,

The equation used is:

$$\frac{dR^2}{dT} = \frac{-2 \quad D\phi \qquad -AC}{\rho_2 \quad 1 + \dfrac{\lambda D\phi C's}{K}} \tag{1}$$

where: AC = change in water content from saturation, lb/cu ft

D = diffusivity of water through air, ft^2/hr

ϕ = ratio total pressure to the partial Pressure of air

TABLE 7 - DROPLET SIZE CHANGES AT 00 F, 1 atm

Original Diameter Microns	1.0	2.5	2.7	5.0	10.0
Stage 1	1.0	2.5	2.7	5.0	10.0
Stage 2	.976	2.49	2.69	4.995	9.998
Stage 3	Evap.	2.29	2.51	4.90	9.95
Stage 4	Evap.	Evap.	Evap.	4.07	9.57

TABLE 8 - DROPLET SIZE CHANGES AT 271 F, 4 psig
7

Original Diameter Microns	1.0	2.5	2.8	5.0	10.0
Stage 1	≥	2.5	2.8	5.≥	10.0
Stage 2	0.96	2.42	2.79	4.99	9.996
Stage 3	Evap.	2.15	2.49	4.84	9.92
Stage 4	Evap.	Evap.	Evap.	3.37	9.29

ρ_2 = density of water, lbs/cu ft

λ = latent heat of water, Btu/lb

k = thermal conductivity of air-steam mixture, Btu/hr ft F

C's = partial derivative of saturated water density with respect to temperature, the derivative taken along the saturation line, lbs/cu ft F

R = particle radius, feet

t = time, hours

The diffusivity was calculated from an equation given by Brown[16]:

$$D = 0.0166 \frac{T^{3/2}}{P\,(Va^{1/3} + Vb^{1/3})^2}\sqrt{\frac{1}{Ma} + \frac{1}{Mb}} \qquad (2)$$

where: T = temperature, K

P = total pressure, atmospheres

Va, Vb are atomic volumes = 29.9, 19.4 for air and water

Ma, Mb are molecular weights = 29, 18 for air and water

The derivative C's was evaluated by considering the effect of pressure only.

$$cs = \frac{P\ 18}{RT} \qquad (3)$$

$$\left(\frac{\partial Cs}{\partial T}\right)_{\text{sat. line}} = \left(\frac{\partial P}{\partial T}\right)\frac{18}{RT}$$

$$\simeq \frac{18}{RT}\left(\frac{\partial P}{\partial t}\right)_{\text{sat. line}} = \frac{18}{RT}\left(\frac{\partial P}{\partial T}\right)\frac{1}{P}$$

The equation for C's is then--

$$C's = \left(\frac{\partial P}{\partial T}\right)\frac{cs}{P}$$

The change in density, ΔC, was also calculated by neglecting temperature change. The steam-air mixture expands isentropically in the nozzle, converting heat energy to kinetic energy and thereby cooling the mixture; but then the kinetic energy is converted to heat energy by friction. The net effect is then a constant enthalpy expansion with little temperature change.

The equation for ΔC is

$$\Delta C = (\Delta P)\ \frac{P_w}{P_t}\ \frac{Cs}{P_w} \qquad (5)$$

$$= \Delta P\ \frac{Cs}{P_t}$$

where: Cs = saturated density of water

= lbs water/cu ft

P_t = total pressure

ΔP = pressure change

P_w = partial. pressure of water vapor

The pressure drop for all four stages is, by direct measurement, 64.8 cm of water for a flow rate of 0.62 cfm at 10? F, 1 atmosphere. This pressure drop was allocated among the four stages on the basis of velocity heads. Table 9 gives the MSA-Cassella jet dimensions and allocated flow constant.

TABLE 9

Stage	Length, mm	Width, mm	Flow Constant, Ci
1	19.0	6.5	0.0275
2	14.0	2.0	0.5357
3	14.0	0.75	3.8096
4	14.0	0.27	29.395

The pressure drop for the i'th stage is:

$$\Delta P_i = C_i\ Q^2 \rho \qquad (7)$$

where: ρ = air-steam density, lbs cu/ft

Q = actual cu ft/min flow

The impactor has four 20 cc chambers. The residence time per chamber is:

$$t = \frac{0.20}{Q)(60)} \qquad (8)$$

where: T = time, hours

Q = liters/min air-steam flow rate

The size change of the particle is then found by squaring the droplet radius, subtracting t times. the change given by Equation 1, and then taking the square root,

$$R^2_{new} = R^2_{old} = t\,\frac{dR^2}{dt}$$

Note that ΔC is computed using the total pressure drop of all previous stages, but not the current stage. For example, there is no change for Stage 1 because, while the gas is exposed t hours in Stage 1, the pressure is still the inlet pressure and ΔC is therefore zero. For Stage 2, ΔC is due to the pressure drop of Stage 1, but not *Stage 2.* For Stage 3, ΔC is the sum of the ΔC's for the first and second stages. The R^2_{old} for Stage 3 is the R^2_{new} from Stage 2.

7. DENSITY OF AIR-STEAM MIXTURES

The equation used to calculate the density of the gas at incident conditions was obtained by making a mass balance of the gas:

$$W_T = Ws + Wa \tag{1}$$

where: W_T = total gravimetric weight of the gas, lb

Ws = gravimetric weight of steam in gas, lb

Wa = gravimetric weight of air in gas, lb

Expressions for the weight of steam and air can be obtained from the definition of moles:

$$Ns = \frac{Ws}{Ms} \tag{2}$$

$$Na = \frac{Wa}{Ma}$$

where: Na = number of moles of air in gas, lb-moles

Ns = number of moles of steam in gas, lb-moles

Ma = molecular weight of air, 28.97 lb/lb-mole

Ms = molecular weight of steam, 18 lb/lb-mole

Substituting the terms of Equation 2 into Equation 1, Equation 3 is obtained:

$$W_T = NsMs + Na\,Ma \tag{3}$$

The number of moles of steam and air can be indicated in terms of the gas properties of temperature, pressure, and volume with the equation of state for an ideal gas:

$$Ns = \frac{PsV}{RT} \tag{4}$$

$$Na = \frac{PaV}{RT}$$

where: Ps = -partial pressure of steam, lb/in.^{2}

Pa = partial pressure of air, lb/in.^{2}

T = absolute temperature of gas, °R

v = volume of gas, ft^3

R = gas constant R in $Pv = nRT$, $\frac{\text{lb/in.}^2 - \text{ft}^3}{°\text{R lb-m}}$

Substituting the equalities of Equation 4 into Equation 3 and rearranging, an equation for the density of the gas results:

$$\frac{W_T}{V} = \frac{MsPs}{RT} + \frac{MaPa}{RT} \qquad (5)$$

The first term of Equation 5 represents the density of the steam and the second term, the density of the air. Since the properties of steam are well known, Equation 5 can be expressed as:

$$\frac{W_T}{v} = ds + \frac{MaPa}{RT} \qquad (6)$$

where: ds = steam density, lb/ft^3

If Equations 5 and 6 were used to calculate the density of'-a saturated mixture of air and steam at 271 F and 61.7 psia, density values of 0.168 and 0.172. lb/cu ft would be obtained, respectively. Equation 6 provides larger values than Equation 5 since Equation 5 represents steam and air as ideal gases.

The density of the gas during Test-12 was calculated below as 0.177 lb/cu ft, based upon the mean total pressure of 61.23 psia, gas temperature of 271 F, and a wet-bulb temperature of 268.2 F (temperature at inlet to separator).

$$\frac{W_T}{V} = 0.1009 + \frac{28.9.7. \times 20.57}{730.7 \times 10.73}$$

$$= 0.177 \text{ lb/cu ft}$$

The temperature at the inlet to the separator.is considered as a wet-bulb temperature since the spray nozzles continuously wet this thermocouple. The air is saturated at this location since sufficient spray flow is provided, and the area of the individual spray particles is large enough so-that sufficient mass transfer between the air and water droplets will occur. Section 8 provides a discussion of the mathematical relationships between the water

8. HUMIDITY CONSIDERATIONS FOR AIR-WATER SYSTEMS

The original concept for this investigation was that tests would be conducted in saturated air at elevated temperature and pressure. It is conventional to assume that the atmosphere in a PWR containment-at incident conditions will be a 100% relative humidity although, for reasons given in Section 3 of this report, there is reasonable doubt that this will actually be attained at the intake to the air-handling equipment. MSA felt that it was important to this program to maintain the inlet fluid as near as possible to 100% relative humidity and made a deliberate effort to insure that this was done. The measured droplet size may be materially affected if the relative humidity is low. However, except for agglomeration by collision with other droplets, it should be constant if the relative humidity is 100%. Unfortunately, no instruments or methods could be found for measuring relative -humidity at the test conditions which would produce results that could not be challenged. Some conventional direct-reading instruments depended on an adsorber which would deteriorate at the elevated temperature; others had no data on response of their sensor at elevated pressure. The following is the derivation of the method-selected as the most accurate. It will be seen that it indicates the testing was done at nearly 100% relative humidity but that, mathematically, it was never completely reached.

The composition of the air stream with respect to water vapor content enters into calculations such as pressure drops or flow rates, affects performance of certain-components to some extent, and exercises a relationship on liquid droplet size and life. The ratio of water vapor present to maximum content possible is commonly expressed as relative humidity defined as:

$$RH = \frac{Pw}{Pws}(100\%) \qquad (1)$$

where: Pw = partial pressure of water in the gas mixture, lb/in.^{2}

Pws = vapor pressure of water at the dry bulb temperature of the mixture, lb/in.^{2}

Wet bulb temperatures were recorded during all tests. For operation at atmospheric pressure, relative humidity is obtained directly from psychometric tables or charts. At elevated pressures and temperature, typical of PWR incident conditions, a mathematical model is used to calculate relative humidity values as developed in the following subsections.

8.1 CALCULATION OF RELATIVE HUMIDITY

The partial pressure of steam in a steam-air mixture at 61.7 psia and 271 F with entrained water droplets was computed by combining the heat and mass transfer Equations 2, 3 and 5 as developed. This partial pressure can then be divided by the vapor pressure at the dry-bulb temperature to obtain the relative humidity. At elevated temperatures with high steam/air ratios, the mass transfer dominates the heat transfer and the partial pressure of water in the steam-air mixture approaches the wet-bulb saturation pressure. At room temperature, with low humidities,. these pressures differ.

The analysis of the relative humidity- consist&of deriving the heat and mass flow equations and performing a heat balance.-

Consider a droplet of water incontact with the air stream. The temperature of this dropletwill be the wet-bulb temperature; i.e., slightly lower than the air which is at dry-bulb temperature. The droplet temperature is assumed to remain constant; the sensible heat of the droplet will be constant and not enter into the calculation. A heat balance can be made for the droplet. There is a temperature difference between the air and the droplet, and heat flows into the droplet. This heat then furnishes the required latent heat to evaporate water which diffuses into the air.

The partial pressure of the water vapor at the droplet surface equals the vapor pressure of water at the droplet temperature (see-Section 8.3). When the bulk gas stream is not quite saturated, there is a partial pressure gradient which allows water vapor to diffuse from the droplet to the air. The droplet temperature is the temperature that balances heat flow toward the droplet with the latent heat consumed as water evaporates and diffuses from -- the droplet.

Heat flux supplied to the droplet is given by:

$$\frac{4}{A} = \frac{K \quad (Ta-Td)}{X} \qquad (2)$$

where: K = thermal conductivity of steam-air mixture

Ta = air temperature, F

Td = droplet temperature, F

x = film thickness, ft

q = heat transferred, Btu/hr

The diffusivity is calculated from the equations of Reference 20 and then the water diffusion rate is calculated.

$$Dg = 0.0166 \left[\frac{T^{3/2}}{P(Va^{1/3} + Vw^{1/3})^2} \right] \sqrt{\frac{1}{Ma} + \frac{1}{Mw}} \quad (3)$$

where: t = temperature, °K

P = pressure atmospheres --

Va = molar volume of air at normal boiling point, 29.9 cc/gm-mole

VW = molar volume of water at normal boiling point, 19.4 cc/gm-mole

Ma = molecular weight of air equals 29

Mw = molecular weight of water equals 18

Dg = diffusivity of water in air, ft^2/hr

The-mass transfer in the "one way diffusion" case -- water diffusing through a stagnant layer is expressed by the following equation:

$$\frac{Na}{A} = \frac{DgP}{RTX} \ln \frac{Pa2}{Pa1} \quad (4)$$

This can be converted to an equivalent heat flow by multiplying by the latent heat of water.

$$\frac{q}{A} = \frac{DgP \lambda Mw}{RTX} \ln \frac{Pa2}{Pa1} \quad (5)$$

where: λ = latent heat of evaporation, Btu/lb

R = gas constant

T = temperature, F

x = film thickness, ft

P_{a1} = air partial pressure in gas distant from droplet, psia

P_{a2} = air partial pressure at droplet, psia

Equation 5 can be solved for the ratio P_{a2}/P_{a1}. The equation becomes:

$$\frac{P_{a2}}{P_{a1}} = \exp \frac{\frac{qx}{A}\, RT}{D_g P\, \lambda M_w} \qquad (5A)$$

Both Equations 2 and 5 require a film thickness to be known. Setting the two equations equal to each other and assuming the heat transfer and diffusion film thicknesses to be equal, an expression is obtained for the partial pressure of the gas in terms of the water droplet and gas temperatures.

The partial pressures of the air are related to the water vapor partial pressure at any particular point by:

$$P_a = P_t - P_w \qquad (6)$$

where: P_t = total pressure, psia

P_w = water particle pressure, psia

The relative humidity is then:

$$RH = \frac{P_w\,(100)}{P_{WS}} = \frac{(P_t - P_a)(100)}{P_{WS}} \qquad (7)$$

where: P_{ws} = vapor pressure of water at dry-bulb temperature, psia

Then, given a wet-bulb temperature, a dry-bulb temperature, and the system pressure, the relative humidity is calculated by these tests:

1. Calculate $\frac{qx}{A}$ by Equation 2A.
2. Calculate D_g from Equation 3.
3. Calculate the ratio P_{a2}/P_{a1} from Equation 5A.
4. Calculate P_{a1}, the partial pressure of air at the droplet surface, from Equation 6. P_w at this point is the saturated water-vapor pressure at the wet-bulb temperature obtained from the published data.
5. Calculate P_{a2}, the partial pressure of air in the bulk stream. Multiply P_{a1} from Step 4 by $\frac{P_{a2}}{P_{a1}}$ from Step 3,

5.2 SAMPLE RELATIVE HUMIDITY CALCULATIONS

At typical PWR incident conditions of 47 psig-271 F, the relative humidity for various wet-bulb temperatures as calculated by the above method gives the following values:

Wet Bulb, F	271	270.5	270	269	268	265
RH, %	100	99.2.	98.2	96.7	95.1	90.4

Since, at this temperature, 'the mass transfer is quite large compared to the heat transfer, the relative humidity could have been accurately approximated by taking the ratio of partial pressure of saturated water at wet-bulb temperature to the partial pressure of saturated water at the dry-bulb temperature. Note that replacement of Steps 1 through 6 by this ratio of partial pressures is not valid at lower temperatures.

8.3 DROPLET SIZE

The selected relative humidity calculations neglect the effect of droplet size. Small droplets have a higher saturation pressure than do large-droplets. The change in vapor pressure due to the curvature of the surface is dependent on surface tension and droplet size. This relationship can be expressed (17) as:

$$\Delta P = \frac{2 P_o \sigma M}{r d RT}$$

where: P_o = saturation- pressure of liquid

σ = surface tension

M = molecular weight

ΔP = vapor pressure increase due to curvature

d = density

r = drop radius

R = gas constant

T = absolute temperature

The effect is small. For example, at 20 C, a droplet 1 micron in diameter would have a vapor pressure 0.2% greater than bulk water: and, consequently, it may be neglected with no serious effect on accuracy of the relative humidity calculation. Impactor bench tests of the 1A atomizing nozzles indicated the presence of

8.4 ADIABATIC HUMIDIFICATION

One can also look at the temperature change which results when air is humidified with no external heat input. If partly saturated air and water at the same temperature are mixed and are kept thermally insulated from any heat source, the air will become saturated as the water evaporates. The- sensible heat given up by the water and air then equals the latent heat required-by the evaporating water.

At one atmosphere pressure, the adiabatic humidification line (equating sensible and latent-heat) coincides with the line equating heat transfer and water diffusion. However, at higher pressures, this no 'longer holds true. Consequently, this approach was not used for the relative humidity deter&nation.

9. SAMPLING METHODS AND PROCEDURES IN THE ETF

The sampling procedure which evolved from the laboratory studies was to be proved by installing a Cassella Impactor on the ETF before and after the moisture separator to sample under ambient and incident conditions.

9.1 SAMPLING AT AMBIENT CONDITIONS

The sampling-module designed for use at-incident conditions was adjudged to be too- cumbersome for use at ambient conditions. Instead, the sampling probe was inserted through two existing 3-inch openings on the top of the outer shell of the ETF. The probe extended through the inner shell and was curved 90 degrees to point upstream. The-sampling tip was 0.51 in. ID to mate the sampling rate to the stream velocity. The downstream probe terminated at a location 10 in. in front of the HEPA at a point slightly below the mid-point of the separator. The'-upstream probewas basically on the same line but sampled at a location abort 18 in. in front of the separator.

The-impactor was housed in an air-circulating constant-temperature enclosure affixed to the outer shell. A schematic of the sampling system is shown in Figure 22. The sequence of steps involved in taking a sample consisted of the following:

The charged impactor was connected to the sampling probe by a single union coupling. The temperature in the impactor housing was maintained at ~5 F above the test stream for at least fifteen minutes before sampling. With the three-way stopcock closed, a purge of dry air was introduced which flushed the sampling probe. Before sampling through the impactor, a two-minute sample was pulled up through the probe and vented through the by-pass installed in front of the impactor. The intent of this step was to ensure that the test stream was brought to the entry of the impactor without mixing with any residual dry gas hold-up.

sampling through the impactor was performed by switching the three-way valve from the by-pass leg to the impactor. Using this procedure, sampling intervals up to 30 minutes at flows of-0.62 cfm were commonly used. At the completion of the sample taking, the impactor was backflushed with dry air.

9.2 SAMPLING AT INCIDENT CONDITIONS

The Cassella Impactor was adapted to operate at incident conditions by encapsulating it in silicone-rubber sealant and installing it in the 6 in. chambers on top of the ETF.

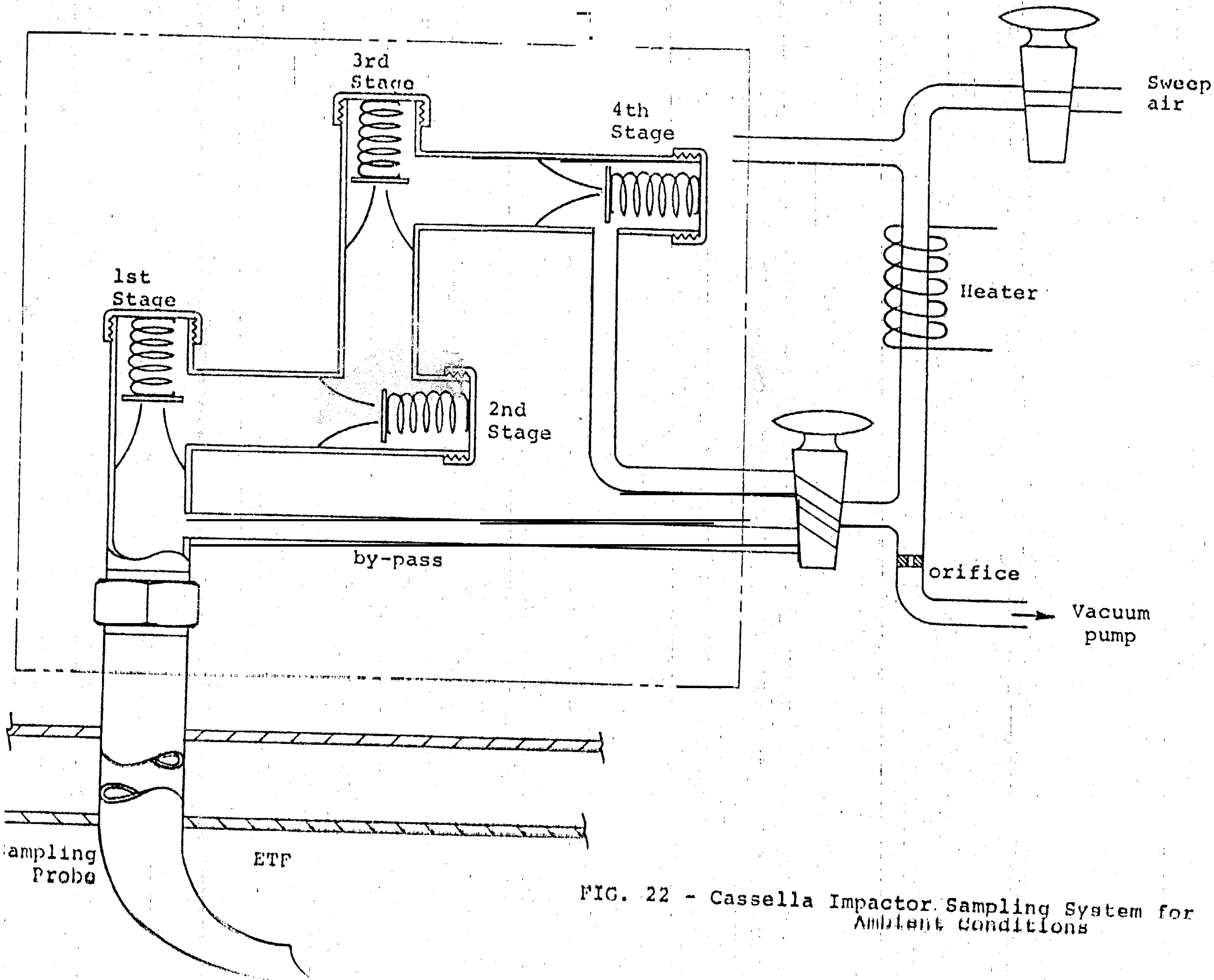


FIG. 22 - Cassella Impactor Sampling System for Ambient Conditions

Basically the same sampling technique described in Section 9.1 was employed, with the exception that the shell was pressurized to equalize the pressure inside and outside the impactor during sampling.

9.3 CHARACTERIZING THE ENTRAINMENT

To establish separator removal efficiency in the <10 micron range, it was first necessary to define the. challenge stream. Characterizing the challenge stream with its high droplet concentration presented a major difficulty. Impaction methods are generally restricted. to low loadings, and the need to use the Cassella Impactor further limited the type of possible solutions-,' Dilution of the challenge stream was given consideration but was felt to be impractical. Sampling by impaction was limited to the use of the 1A nozzle which was the source of fine particles and had been tested in the laboratory. The manufacturer's data were- used to identify the challenge stream when the coarser sprays were used.

9. 4 ENTRAINMENT AT AMBIENT CONDITIONS.

The selected approach to circumvent the high loadings was to estimate-the challenge stream by extrapolating the data obtained at lesser loadings which were more favorable to the use of the' impactor. Figure 23 shows the mass distribution curves of the entrainment in the ETF when supplied by a single 1A nozzle and, again, using a bank of five 1A nozzles. Data were collected in the ETF at 1600 cfm (400 fpm velocity) at ambient conditions. In general, the method of sampling and the operation of the ETF was basically the same as would be employed in a separator test.

Samples were collected at the downstream sampling port with no separator in use and reflect only that portion of the generated mist which survived passage,, through the cooler. The ETF was first-stabilized with respect to relative humidity (>98%) using all the-nozzles, and then impactor samples were taken immediately after returning the system to either the-l- or S-nozzle source. The results are presented in Figure 23 as the accumulated mass percentage veksus particle size in the 2.5 to 10 micron range. These results indicate a shift in the entrainment distribution toward the finer particles when using more nozzles for increased loading. Undoubtedly, loss of the finer material would be more prevalent where only a single nozzle was used; hence, the data obtained with the five nozzles were used as a base. In this manner, for example, a 30-nozzle system was assumed to have the same distribution but a six-fold increase in total mass. Verification of these data was attempted by resorting to a "grab sampling technique" taken from a fully loaded test stream (39 nozzles). The results were erratic. The data

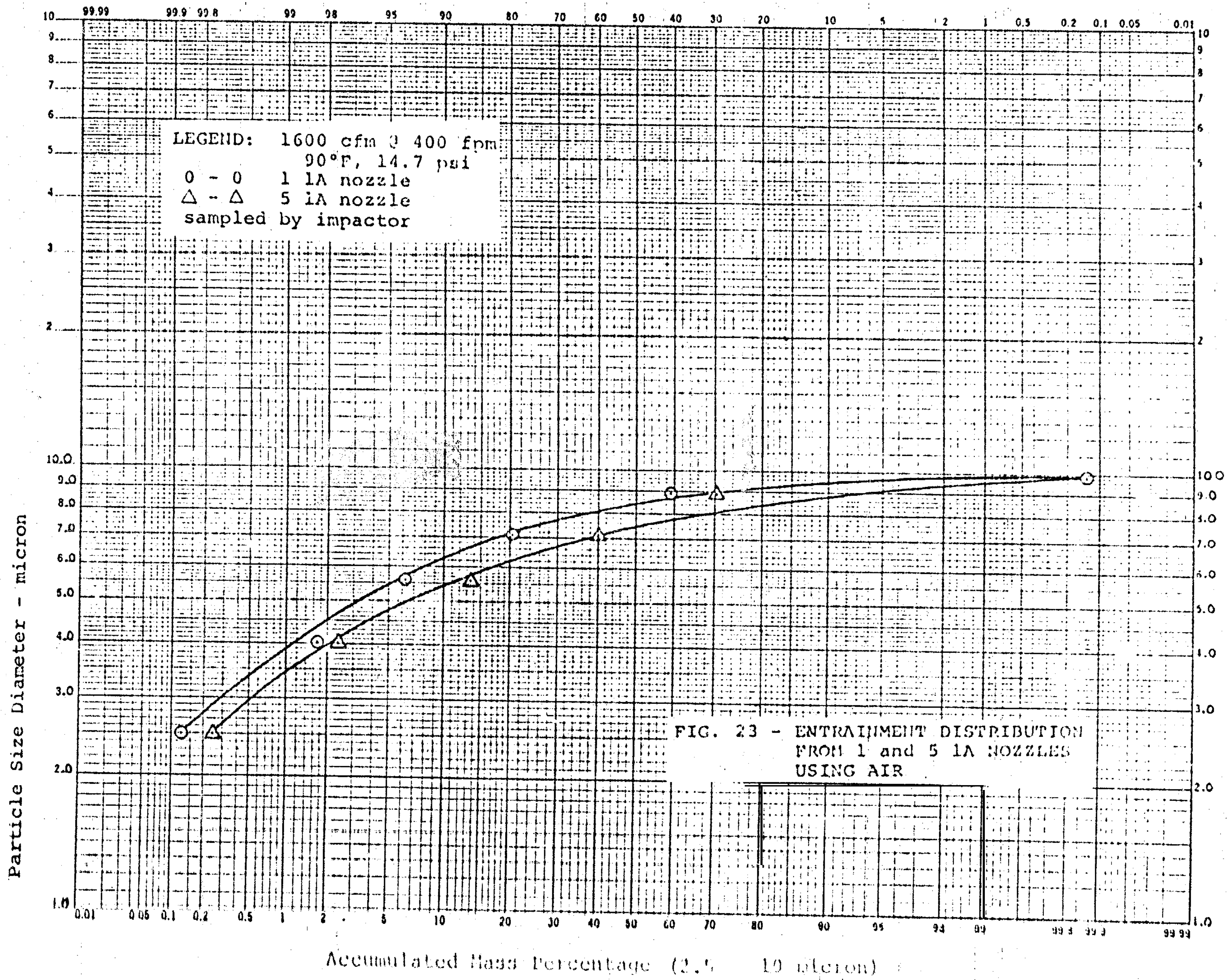


FIG. 23 - ENTRAINMENT DISTRIBUTION FROM 1 and 5 1A NOZZLES USING AIR

The differences in rated flows among the several separators was not considered sufficient to cause any significant changes in entrainment distribution. No testing was done to investigate entrainment at greater variations in flow.

Using the total mass found on the impactor slides for five 1A nozzles, it was calculated that each 1A nozzle was contributing 0.0019 lbs/hr of droplets in the measurable range of 2.5 to 10 micron. The rated capacity, including all sizes of particles for this nozzle at 8 psi differential pressure, is about1 lb/hr (Table 2). Based on. this total rated vapacity, the percentage of mass less than-10 micron as found by the impaction method was 0.19%, which is considerably less than the value of 0.5% obtained -by extrapolating the approximations suggested by the manufacturer -(Figure 16).

One problem found with the 1A nozzles was their susceptibility to plugging. An attempt was made always to start a test with all the nozzles operating but, in most cases, they started plugging early in the test, as -evidenced by the reduced water removal by the separator. The maximum removal measured was 6.4 lbs/hr at the-beginning- of one run, and it can be assumed that all the nozzles were open and producing 39 lbs/hr, based on information from the manufacturer. If this was actually the case, then only 16.4% of the water droplets reached the separator and the rest were lost by impaction and agglomeration along the way. As pointed out in the preceding paragraph, the impactor results indicated 0.0019 lbs/hr as compared to 1.0 lb/hr being generated by a nozzle. Assuming only 16.4% or 3.164 lbs/hr reached the impactor nozzle, the impactor was measuring only 1% of the total water. This does not mean that the impactor was inaccurate because it was measuring only in the 2.5 to 10 micron range and the quantity of water in this range is not known.

Table 3B was used in an attempt to determine the weight of particles above and below- 10 micron and the calculation indicates 21.3% of the liquid is in particles 10 micron and below. Unfortunately, the liquid used or the conditions of atmoization are not known other than the fluid and gas were both at 15 psi. Since this was an atomizing nozzle, the concentration of fine particles should be higher than for a 1A nozzle.

While the impactor results, were not entirely satisfactory, it did appear that if small droplets were present in the air downstream of the separators the impactor would give a possible indication, even though the results would probably be on the low side, Since this seemed to be the best tool available to evaluate the size and concentration of water particles, the decision was made to contfnue with the Cassella Impactor.

9.5 ENTRAINMENT AT INCIDENT CONDITIONS

The fine droplet (2.5 to 10 micron) distribution of the entrainment from the 1A nozzle at incident conditions is shown in Figure 24. In general, the curve obtained at incident conditions, in which atomization by steam instead of air was used, approximates the distribution obtained at ambient- conditions. It was also found that the mass of droplets generated using steam was considerably less than the mass delivered with air at ambient condition, The mass of fine particles determin'ed using steam was 0.00081 lb/hr per nozzle. Small-scale laboratory studies, at 212 F and 30 psi, in which water feed to the siphon was measured, indicated that a 25:1 decrease in total output might result when steam was used in place of air. The nozzle manufacturer stated that a slight reduction in output might result from the use of steam.

A breakdown of the various particle sizes is shown in Table 10. Visual inspection of the challenge stream showed a fog concentration estimated to be about 50% of that at ambient. The total water reported by impactor measurements is 2 x 10^{-3} mg/cuM which is well below the visible range.

TABLE 10 - FINE PARTICLE DISTRIBUTION MEASURED FOR 1A NOZZLES USING STEAM IN THE ETF

Particle Size, μ	Challenge Stream Mass lbs/cu ft, 273 F, 47 psi	mg/cuM
2.5	2.42 x 10^{-12}	0.388 x 10^{-5}
4.0	41.2 x 10^{-12}	6.6 x 10^{-5}
5.6	116 x 10^{-12}	18.6 x 10^{-5}
7.2	440 x 10^{-12}	70.5 x 10^{-5}
8.8	361 x 10^{-12}	57.8 x 10^{-5}
		1.98 x 10^{-3}

These results are misleading when the measurable water fall-out and visible mist downstream of *both the Farr* and Monsanto Separators are considered, It appears that when water particles were present, the impactor would give an indication but the results were not quantitative, In Section 9.4, it was noted that when the spray was characterized the impactor indications were below the manufacturer's theoretical values by a factor of 2.5. It is significant that when there was ... visible ...

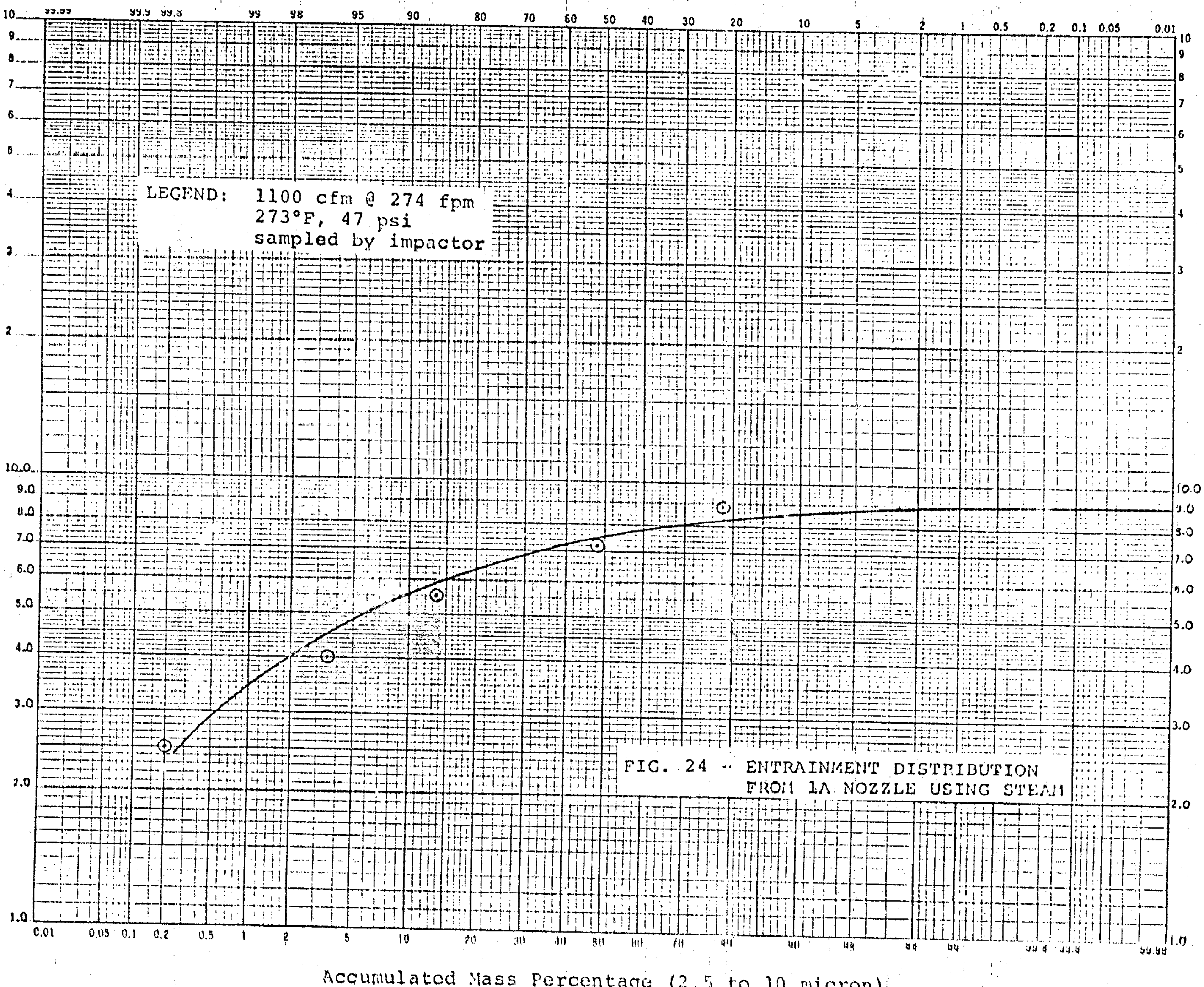


FIG. 24 -- ENTRAINMENT DISTRIBUTION FROM 1A NOZZLE USING STEAM

9.6 VISUAL OBSERVATIONS OF WATER PARTICLES

Observance of the fog through the sight glass upstream of the separator indicated a rather dense concentration. An attempt has been made to correlate this with known facts about atmospheric fog. Information has been-secured from the literature and visual observations of actual fog have been made by MSA personnel. In the MSA Catalog, Section 10, Technical Information, on pages 57 and 59 (shown as Figures 25 and 26), there is information on fog concentration and particle size. In Figure 25, visibility in feet is compared to the concentration of water in air in mg/cu M. The concentration to be consistent with test observations is converted to lbs/cu ft for this discussion. At a concentration of 3×10^{-6} lbs/cu ft, the visibility *is* approximately 5000 feet/and at *a* concentration of 4×10^{-3}, it is approximately 40 feet. Observations of actual fog in daylight, as the fog density was increasing, indicate that when the visibility is as low as 500 feet there are not ancugh particles in 2-4 feet to see them. In the ETF, the depth of field was 2 to 4 feet, so any visible particles represented a large concentration if the observations of actual fog held true. At a removal rate of 2.5 lbs/hr for a separator, the upstream air contained 2.6×10^{-5} lbs of water/cu ft.

-The Cassella Impactor was used to measure the size of fog particles and the results of 2-50 micron checked very- well with the results of 2-40 micron shown in Figure 26. The reported results are credited to three different investigations and it is not known what method was tied to measure the particle size. If a Cassella Impactor was used in each case, it might be said that the results should agree whether they are right or wrong; however, since its use has been so extensive, it is assumed that size measurements are fairly good.

If reference is made to Figure 25, it can be seen that the lower visible range of fog is 5 mg/cu M and the impactor results, reported in Section 9.5, are 2500 times less than this. One of two conclusions can be drawn from this -- either the majority of the particles is above 10 micron and not measured by the impactor; or the impactor is not capable of quantitatively measuring the small particles. If the first is true, almost any separator will remove the large. particles and there will be *no* visible particles in the downstream air; however, if the second is true, there may be visible particles downstream of the separator even though the impactor indicates a low concentration. Actual testing will verify which of these is true.

the concentrations of materials in the air

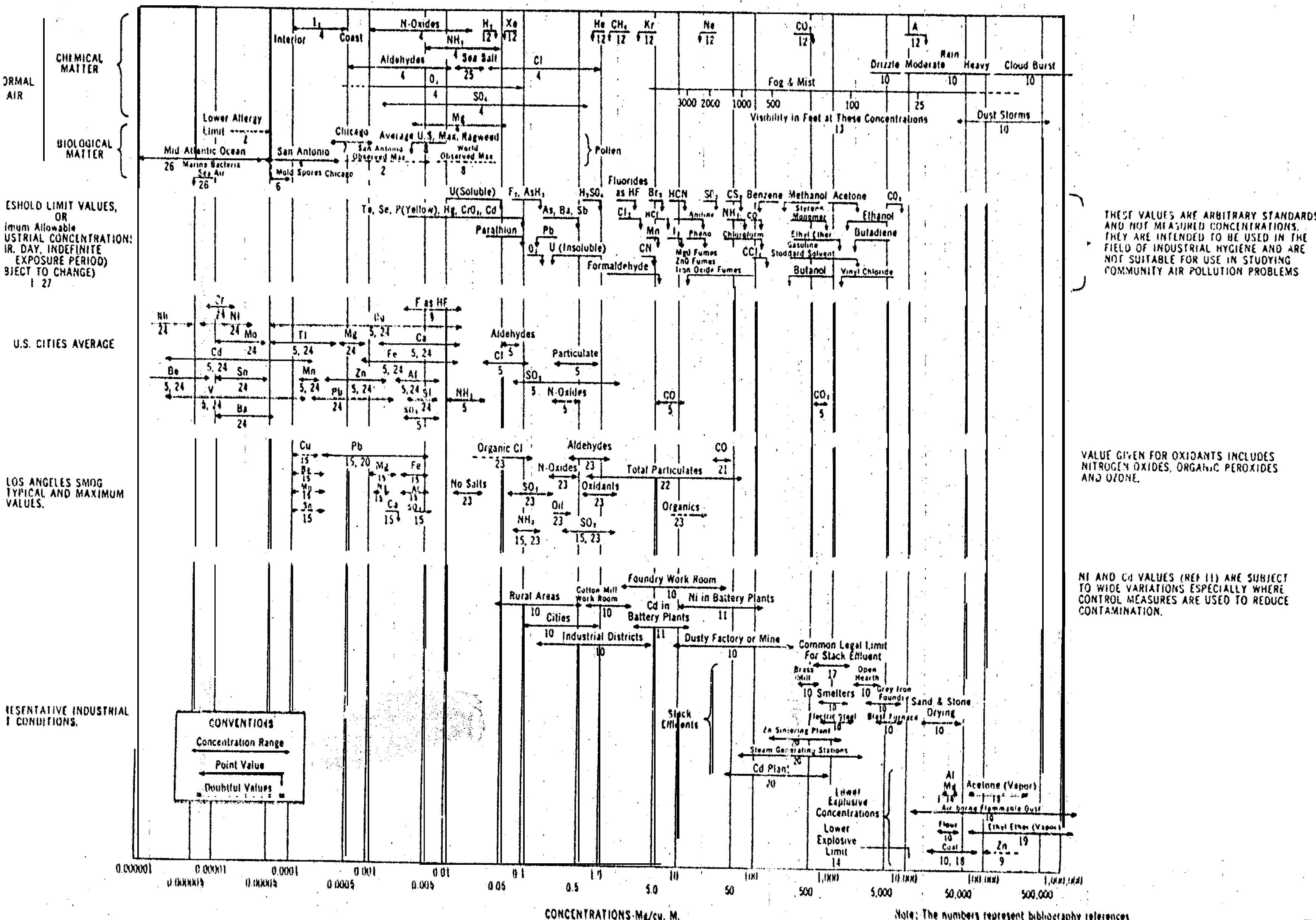
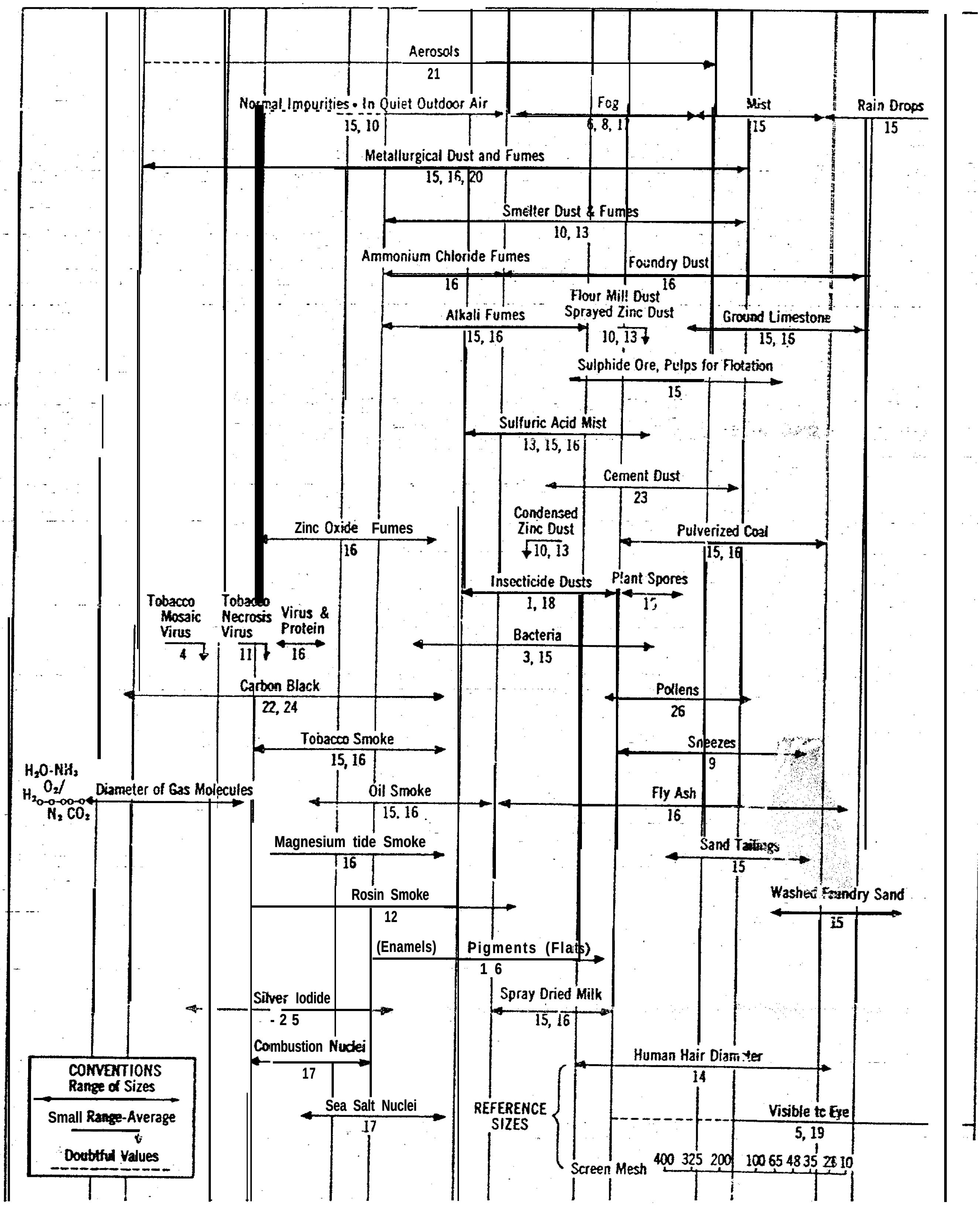


FIGURE 25

the sizes of air-borne contaminants



10. ENTRAINED MOISTURE SEPARATORS COMPARISON SUMMARY

The five moisture separators tested in this program are shown in Figures 27 through 36. A complete description of each separator, the method of installation, and a discussion of the test results can be found in the Appendix.

Test procedures used were outlined in Section 4, with modifications as necessary for the individual separators. Test conditions were essentisily the same for the five separators but some variations were necessary to meet the manufacturers' recommended operating conditions. The primary difference was in air flow which varied from 1140 to 1800 cfm, as shown in Table 11.. An unintended difference occurred in the water spray rate from the 1A nozzles during ambient and incident tests. The extremely cold weather resulted in a shortage of atomizing steam at times, and the small nozzles had a tendency to plug, even. though there was a fine filter in the line, causing the flow to decrease.

10.1 SEPARATOR SIZE

The size of the separators was uniformly held to 24 x 24 in maximum face dimensions to fit the ETF. This is the general standard size for most commercial separators, except possibly the AAF module. Based on rated flow for this size of unit, the rating in square feet of separator cross-section per 1000 cu ft of rated gas flow is tabulated. On this basis, minimum installation space required for a given flow rate is provided by the Monsanto separator, followed closely by the Farr separator, and then the York and MSA separators -- all within 15% of each other: 2.2 - 2.5 sq ft/1000 cu ft. The AAF separator requires the largest -installation space of 3.5 sq ft/1000 cu ft -- 40-60% more than the others.

Installation depth varies from a low of 2 in. for the Monsanto to 5 in. for the MSA and to 24 in. for the AAF separator; -- about 5-12 times more than the others, exclusive of access space, Weight comparisons vary from 20 lbs for the York: to 111 lbs for the AAF; the latter weighing more than any of the others by a factor of 3.5 to 5.5. In all these comparisons, both the Monsanto and York separators will need provisions for minimizing reentrainment and weight and space for these must be added to the basic values given.

10.2 PRESSURE DROP

Pressure drop at rated flow using standard air both without and with entrainment was lowest for the Farr (0.27 - 0.35 in, WC) followed closely by Monsanto (0.32 - 0.42); then by AAF (0.78 - 1.20) MSA (0.97 - 1.35) and York (1.24 - 2.22). -These pressure drops increased 20-70% with maximum entrainment loading tested at ambient

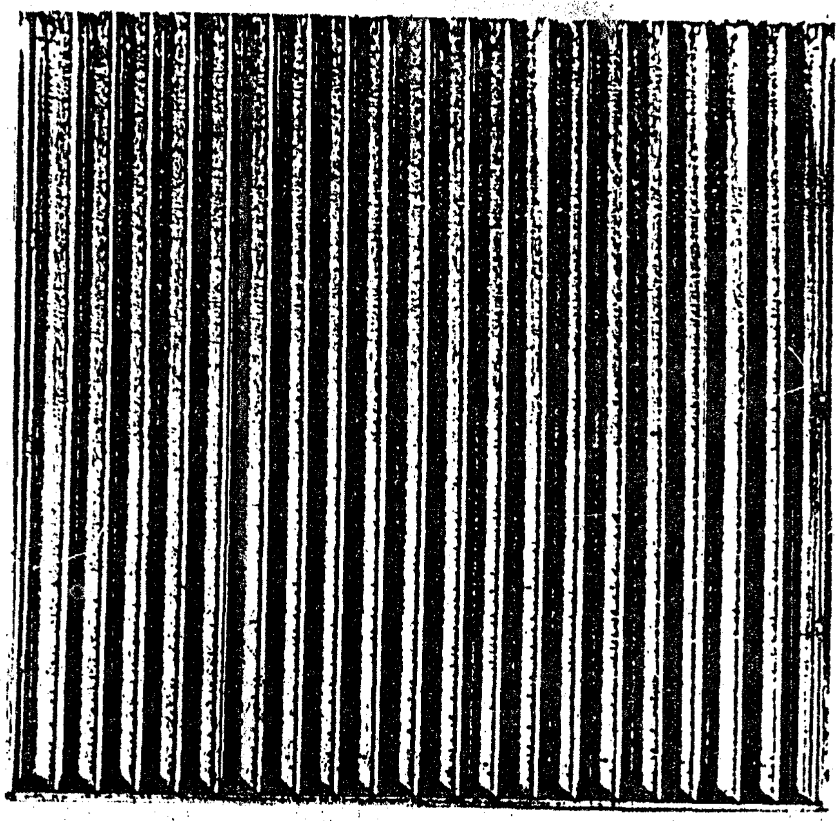


FIG.27 - MONSANTO SEPARATOR INLET

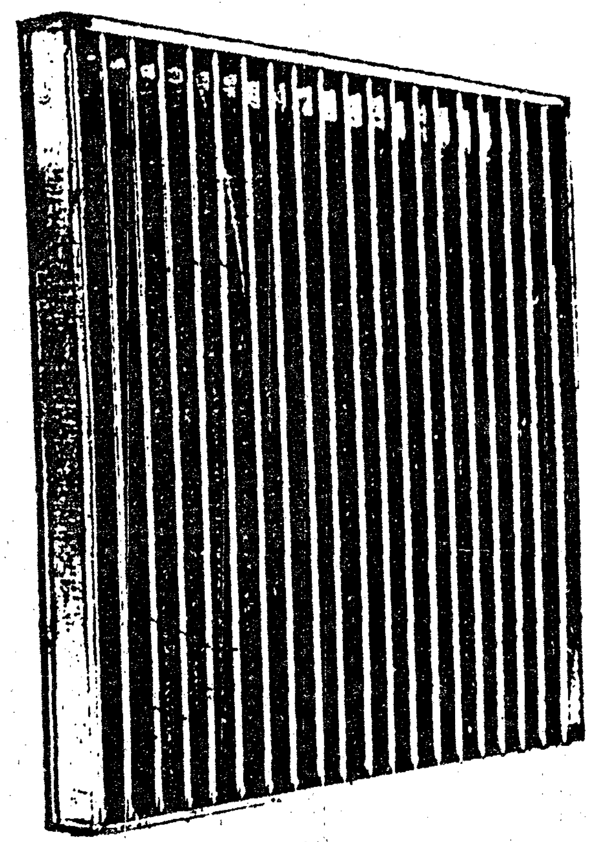


FIG.28-MONSANTO SEPARATOR OUTLET

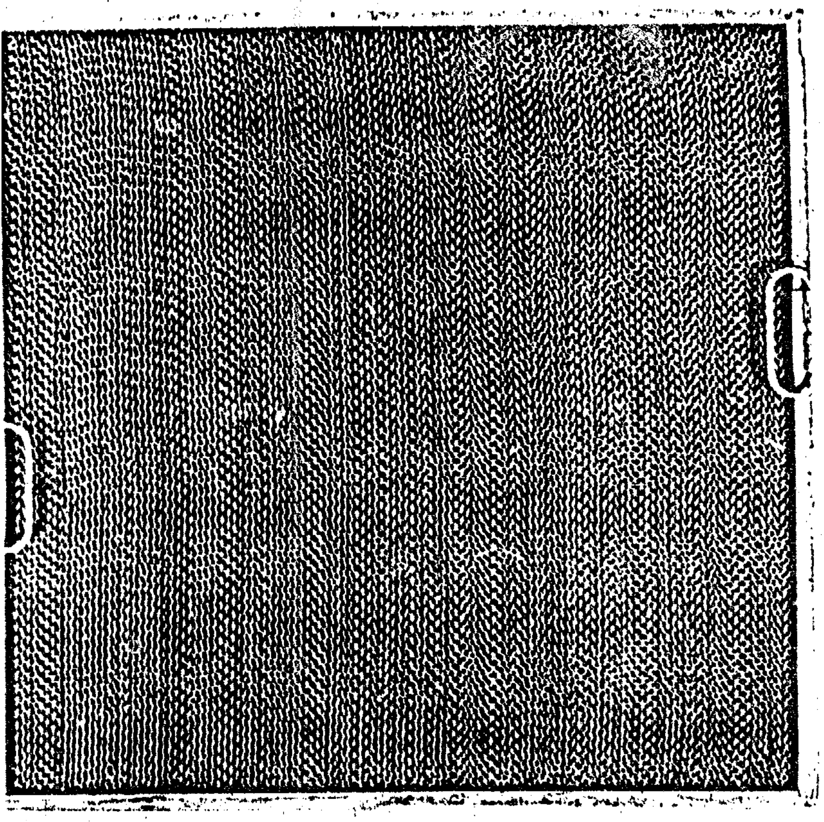


FIG. 29 - FARR SEPARATOR INLET

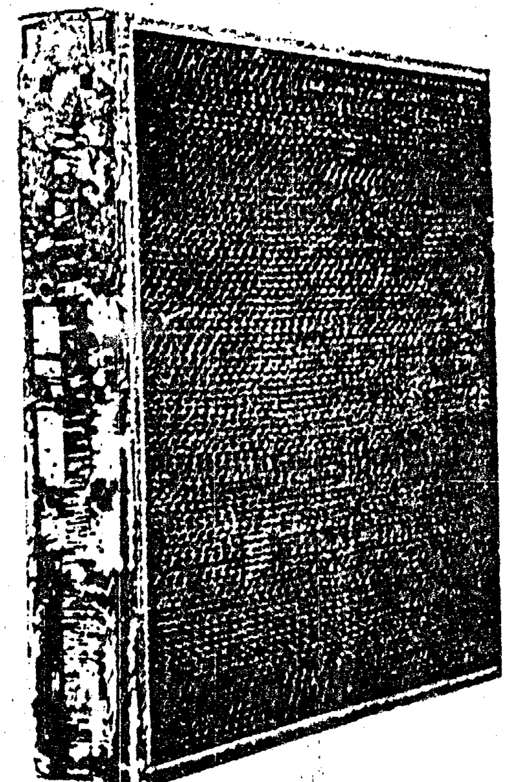


FIG. 30 - FARR SEPARATOR OUTLET
SHOWING BOTTOM DRAINS

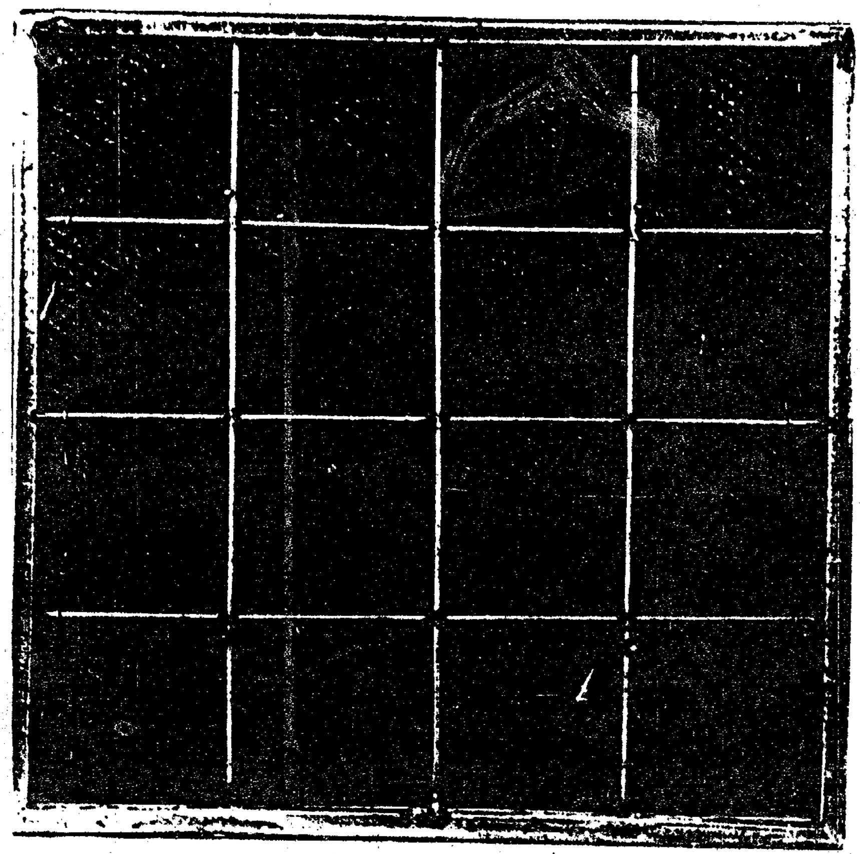


FIG. 31 - YORK SEPARATOR OUTLET

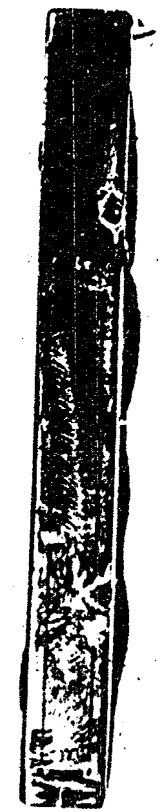


FIG. 32 - YORK SEPARATOR SHOWING BOTTOM DRAINS - OUTLET ON RIGHT

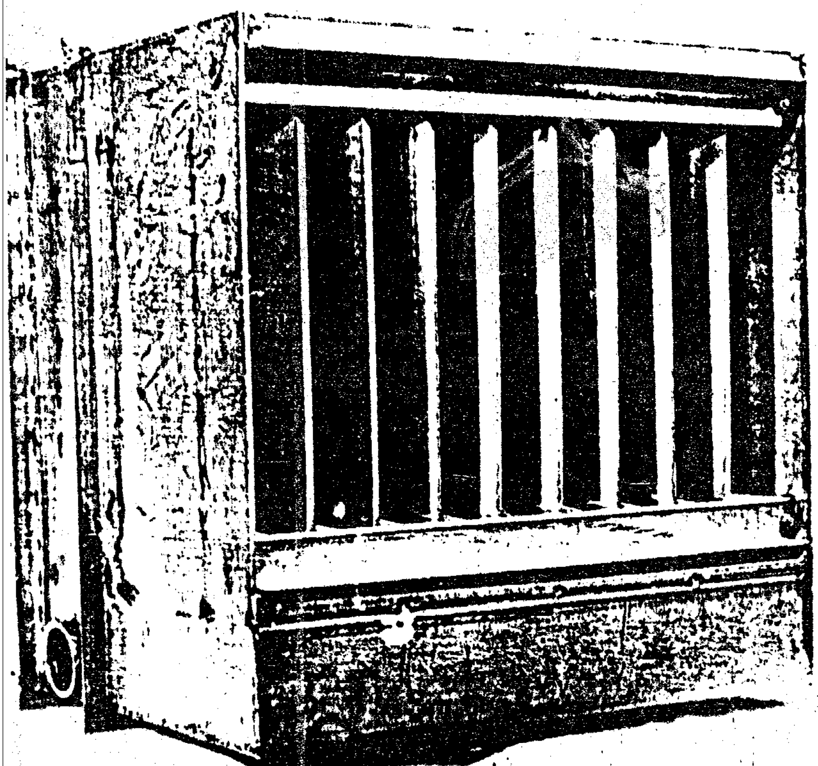


FIG. 33 - AAF SEPARATOR INLET

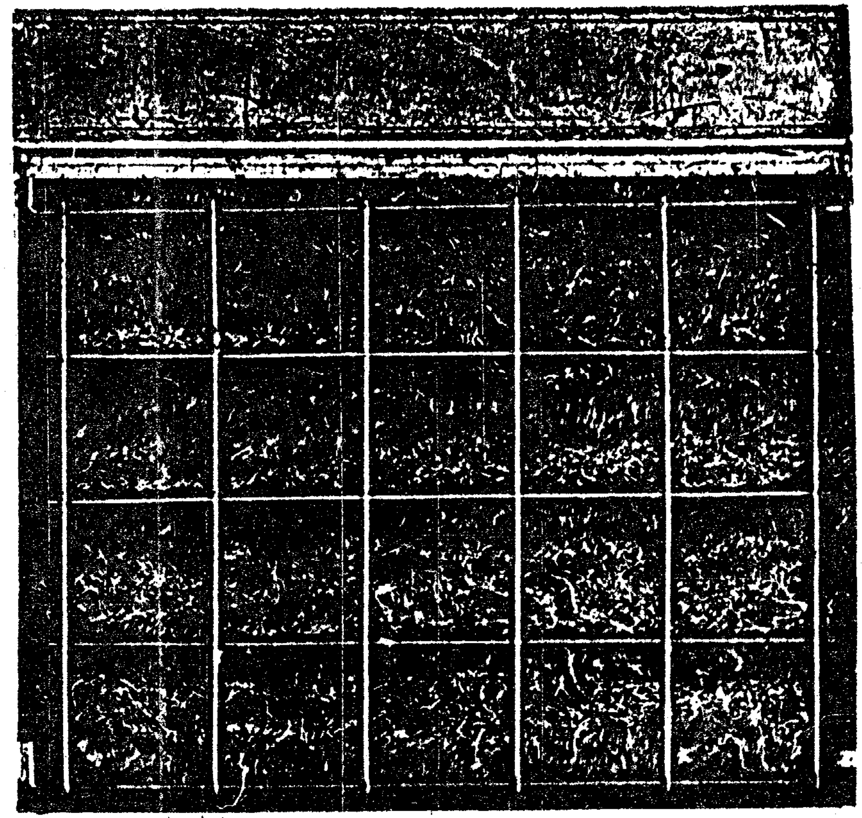


FIG. 34 - AAF SEPARATOR OUTLET

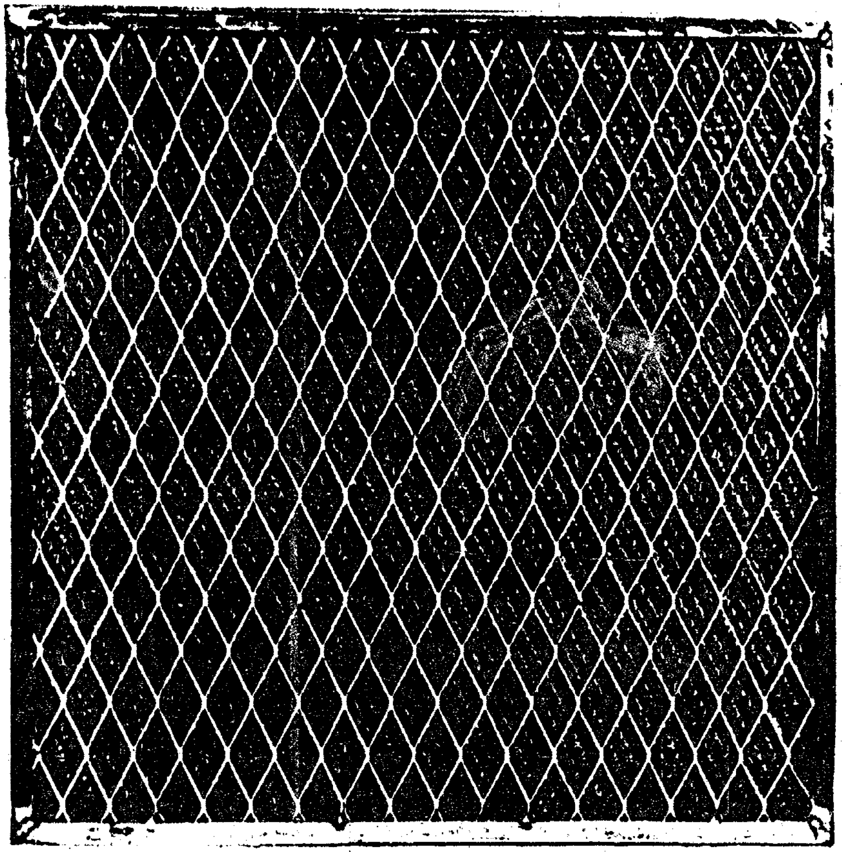


FIG. 35 - MSA SEPARATOR INLET

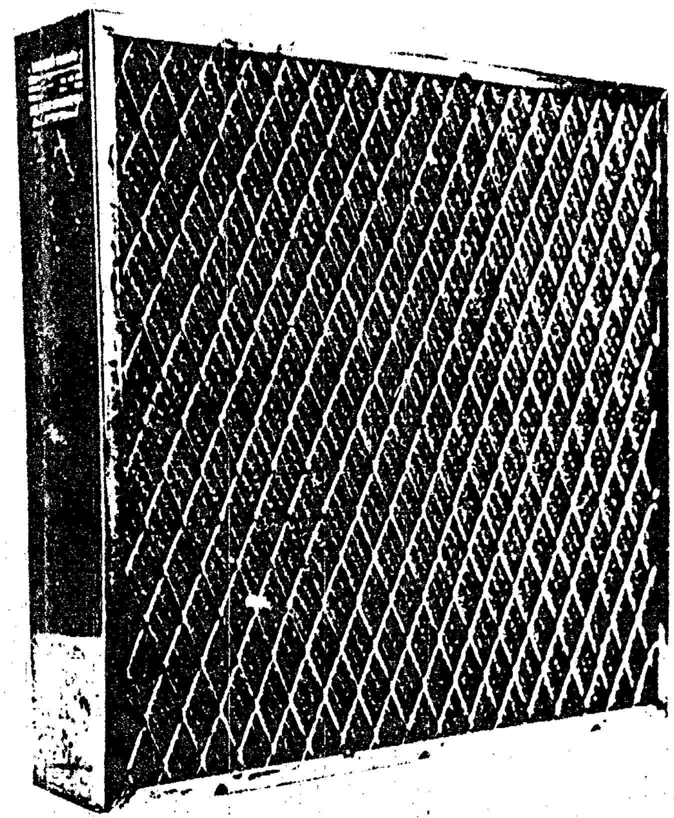


FIG. 36 - MSA SEPARATOR OUTLET

TABLE 11 - COMPARISON OF SEPARATORS

ıturer	Monsanto	Farr	York	AAF		MSA		MSA	
:or Model Number	Baffle Typo 1	(po 68-44 MZH 7010	Type 321 SR TY-5	Type T 491-118		Type G 1234-2		Type G 1234-1	
.nches	24 x a4 x 2	1 x 24 x 4	4 x 24 x 2.t	24 x 24 x 24		24 x 24 x 5		24 x 24 x 5	
F/MCF	2.22	2.24	2 . 5	3.5		2.5		2.5	
eight - lbs	26	32	20	111		30		30	
'low, CFM	1800	785	600	1140		1600		1600'	
Flow, in. WC	0.12	0.17	1.24'	0.711		0.90		1.03	
OP-Penetration %	100	100	93	95		96			
OP-Penetration %	98	99	69	93		80		78	
Number	T-18	T-19	T-20'	T-21	T-24	T-22	T-23	T-14A	T-14
'F - Pressure psig	100 - 0	96 - 0	96 - 0	88 - 0	271 - 47	100 - 0	271 - 47	80 - 0	271 - 4[illegible]
ıment									
emoval, lb/hr	61.7	566	33.4	311	50 100	496	28, 55	112	22, 47
ration, lb/hr	0.37	0	94.2	0	0	0	0	0	0
iency, %	>99	100	26	-100	~100	~100	~100	100	-100
μ Removal, lb/hr	717	738	18	444	0	651	0	0	56
enetration, lb/hr	0.37 t Mis	0.29 + Fog	100.2	0	-	0	-	Flow Test to 2100 CFM only, at constant loading of 560 μ and 110 μ MVD	0
fficiency, %	>99	99	16	~100	-	~100	-		~100
moval, lb/hr	3.66	2.9	.81	6.4	<1	2.5	<1		0
enetration, lb/hr	0.37 + Mis	0.29 + Fog	1.44	0	0	0	0		Not Available
fficiency, %	<91	<91	36	~100	~100	~100	~100		
or △P, in. WC									
mbient	0.35	0.26	1.29	0.80	0.88	0.93	0.88	1.00	1.00
aximum	0.42	0.35	2.22	1.20	1.89	1.40	1.88	1.30	1.73
ase %	20'	35	72	SO	115	51	114	30	73
Changes	None	None	None	Fibers Loosened	Fibers Darkened, Binder Loss	None	None	None	None
, in. WC									
mbient	1.81	1.77	1.57	1.08	1.08	1.52	1.55	Not used; visible observation only.	1.40
aximum	1.97,'	2.02	1.79	1.31	1.40	1.76	2.20		2.30
ase %	20	33	1 4	21	30	16	42		64
Gain, lbs	0.94,	0.63	0.88	0.94	-	0.63	-		0.50
OP Change	None	None	None	None	None	None	None	None	None

ETF conditions. The percent of increase was least for Monsanto at 20%. Farr, at 35%, still showed the lowest total pressure drop. MSA at 408, AAF at 50% and York at 72% showed the highest increase at the lowest tested entrainment loading rate,

10.3 DOP PERFORMANCE

The 0.3 micron DOP penetration results tabulated for the various separators indicate at best that the York,. AAF and MSA separators show a measurable attenuation-of particles in this size range, while the Monsanto and Farr separators gave no measurable response. Repeat measurements of units.-in this high penetration range have varied-by ± 5%. Thus, numerical comparison of values reported in the upper 90% penetration range can be interpreted only as showing or not showing a 0.3 micron particle size attenuation response,

The 0.6 micron Do? penetration results tabulated for the various separators similarly lose reliability of interpretation at penetration levels measured in the upper 90% range.'- Thus, the Monsanto and Farr penetration values may indicate only a slight attenuation response for 0.6 micron particles. The values tabulated for the other separators show that the highest removal efficiency for 0.6 micron size particles is obtained by the York separator (69% penetration) followed by MSA (79%) and the AAF (93%). Other York separators gave measured 0.6 micron DOP penetration to 73% at 1.30 in. WC. If these separators were reduced in media content to hold 1.0 in. WC (DP812[7] maximum allowable),-penetration can be expected to reach ~80%. This is comparable to the values normally reached with MSA separators as measured for the two units tested here and based on HSA product&@ lot results for both Type G and Type T separators,

10.4 EFFICIENCY

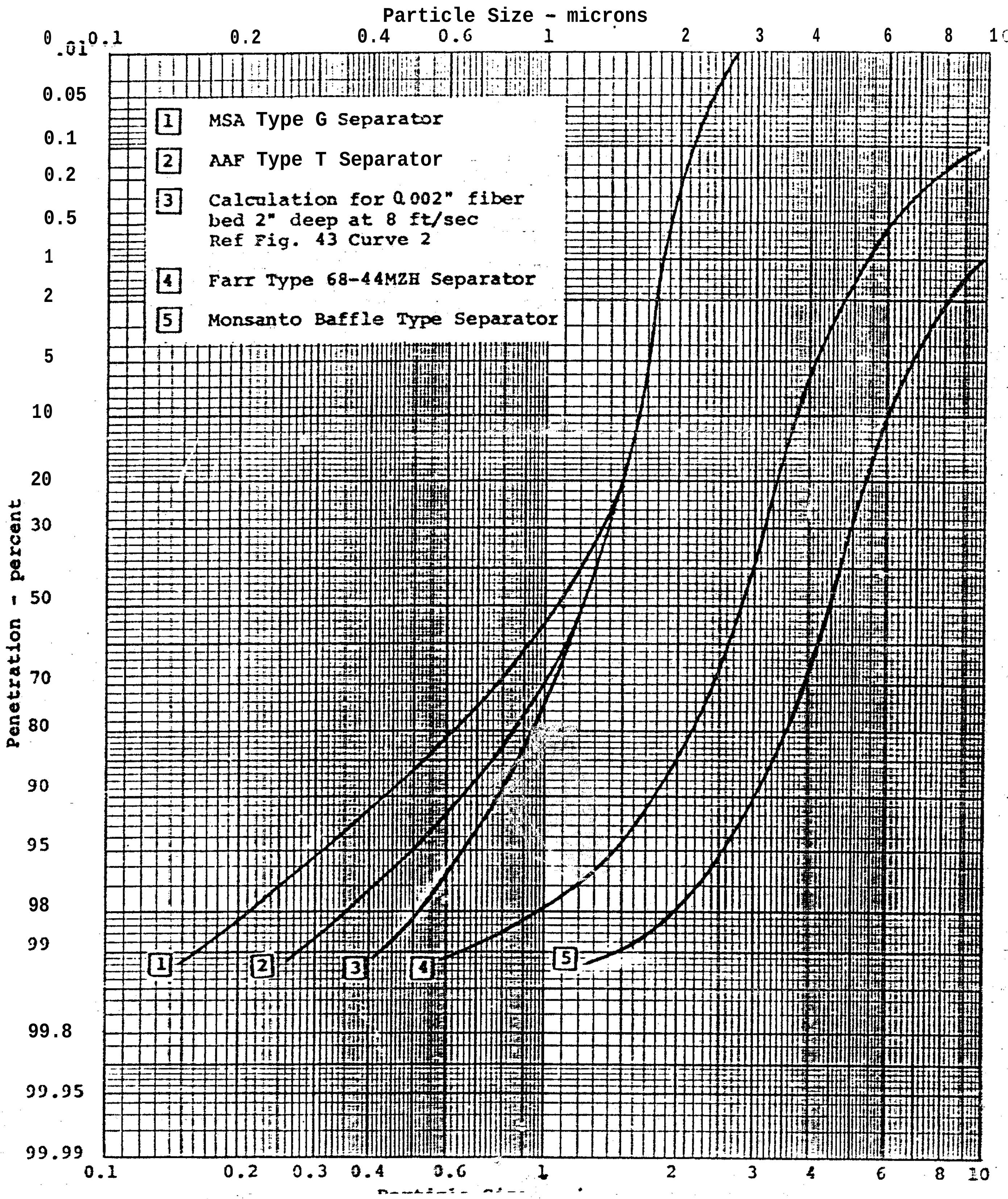
Entrainment removal efficiencies of the tested separators are summarized in Table 11, according to approximate MVD particle size. Most efficient (~100%) were the AAF and MSA separators at no detectable penetration in the ETF at either ambient or elevated operating conditions. The Farr separator is rated more efficient than the Monsanto on several points: at 100 micron MVD, there was no measurable penetration dropout; at10 micron MVD or together with 70 micron, a lower penetration dropout rate was measured, visible entrained penetration appeared as wisps of fog rather than the more uniform mist; and finally impactor sampling gave higher efficiencies for the Parr separator, Least efficient was the York separator. This is based on 16-36% removal efficiency within the separator case with the balance being reentrainment in the effluent stream which was carried up to 18 in. downstream of the separator to within 6 in. of the monitoring HEPA before...

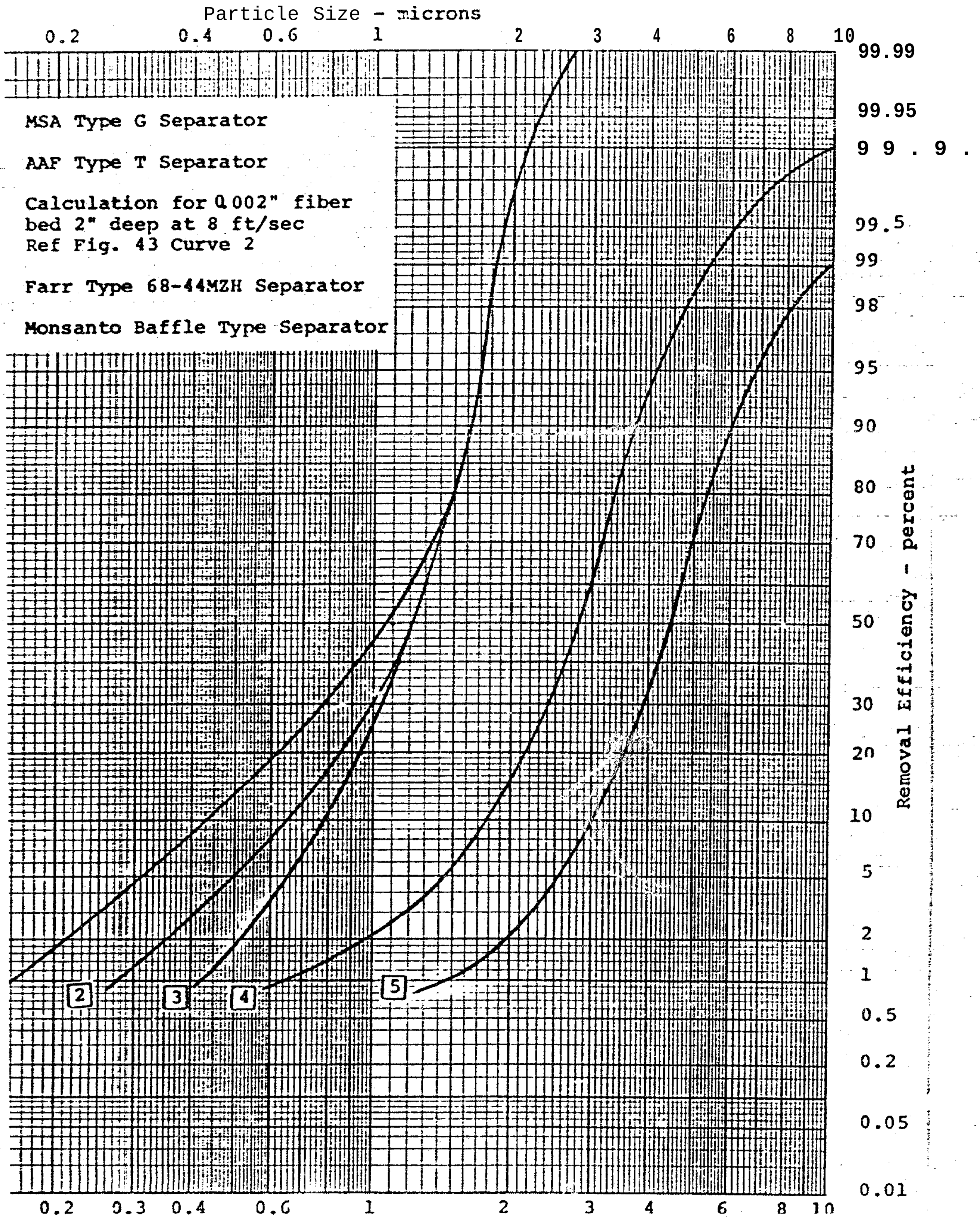
units in height, the lower HEPA filters would be deluged with re-entrainment unless protected by intervening distance or mechanic& means of removal.

Predicted efficiency curves for these-tested separators in the <10 micron size range are presented in Figure 37. The calculated efficiency for a typical fine fiber media bed *is* presented in Figure 37 as Curve 3 (taken from Figure Cl, Curve 21. This curve was derived by Savannah River for performance comparison by analogy to the media bed comparison of the York separator. MSA failure *to* detect any penetration down to 2.5 micron verifies agglomeration efficiency equal' to or greater 'than the upper calculated values. The 0.3 - 0.6 - 1.1 micron DOP values for this Teflon media indicate slightly better agglomeration values than originally calculated in the lower submicron particle size range. Since this plot shows entrainment removal values instead of fine particle agglomerating values, including the York separator efficiency on this plot would be misleading.

Removal efficiency curves for both the MSA (1) and AAF (2) separators are assumed to follow-closely the calculated values of Curve 3 in the larger particle size range based on no detectable penetration visible, measurable as reentrainment dropout, or by impactor sampling of effluent gas to 2.5 micron particle size. In the submicron particle size range, the MSA separator is judged slightly more efficient than the AAF separator based on DOP measurements, All MSA production history has verified 0.6 micron DOP measurements at a normal level of 80 ± 5% penetration, within which the two tested separators fell. Comparison of MSA glass with Teflon media has shown about equal response with 0.6 micron DOP. At 1.1 micron DOP test levels, typical MSA Teflon media indicate ~40% penetration, 60% removal at 1 in. differential pressure, which should again be comparable to the Type G media-.- The 0.3 micron DOP results are probably firm at near 95% penetration, since previous Type G separators have given values from 86 to 98% penetration. Thus, the efficiency curve for the--MSA-Type G Separator diverges from calculated Curve 3 in the submicron size--range by following the measured DOP data points. The AAF Type T separator curve also diverges from Curve 3 in the submicron range based on the rather firm 0.6 micron DOP penetration measurements of 93 - 95 - 92% made on this unit *over the course* of testing, The single 0.3 micron DOP measurement of 95% penetration made is rejected in favor of the more extensive and reliable 0.6 micron DOP measurements made.

Removal efficiency of the Farr Separator (Figure 37, Curve 4) was predicted as being somewhat less than impactor -sure.-- - - , since these are based only on that size particle remaining entrained in the effluent gas stream. Conceivably a good portion of particles in #is size range entering the separator are agglomerated to an intermediate size. preventing removal within the


Particle Size - microns
0.01
0.1
0.2
0.4
0.6
1
2
3
4
6
8
10
0.05
0.1
0.2
0.5
1
2
5
10
20
30
50
70
80
90
95
98
99
99.8
99.95
99.99
Penetration - percent
1 MSA Type G Separator
2 AAF Type T Separator
3 Calculation for 0.002" fiber bed 2" deep at 8 ft/sec Ref Fig. 43 Curve 2
4 Farr Type 68-44MZH Separator
5 Monsanto Baffle Type Separator
1
2
3
4
5
0.1
0.2
0.3
0.4
0.6
1
2
3
4
6
8
10



Particle Size - microns
0.2
0.4
0.6
1
2
3
4
6
8
10
MSA Type G Separator
AAF Type T Separator
Calculation for 0.002" fiber bed 2" deep at 8 ft/sec Ref Fig. 43 Curve 2
Farr Type 68-44MZH Separator
Monsanto Baffle Type Separator
2
3
4
5
99.99
99.95
99.9
99.5
99
98
95
90
80
70
50
30
20
10
5
2
1
0.5
0.2
0.05
0.01
Removal Efficiency - percent
0.2
0.3
0.4
0.6
1
2
3
4
6
8
10

measured performance of 0.006 in. dia. media reported by Elam[19]. Thus removal performance for liquid droplets is estimated considerably higher than the values reported for dust by Farr (Figure B1) for the larger (5-10 micron) particles; below the Farr values and equal to Elam values in the 2-3 micron size; and approaching a "DOP response" value in the 0.6 micron particle size.

Removal efficiency for the-Monsanto baffle-type separator is similarly predicted to have an eff-iciency response as shown by Figure 37, Curve 5. By analys-is similarto that reviewed for the Farr separator, the-removal efficiency closely parallels that- for Farr but at somewhat reduced-levels for each particle size.- The 0.6 micron DOP measurement again indicates detectable attenuation of particles down to this size. This level of response is comparable to that for 0.011 in. dia. x 16 lb/cu ft wire giving 99-98-97% penetrations for 1-2-3 in. thicknesses, respectively, at 400-500 fpm. Below 200 fpm, 0.6 micron DOP penetration was 100% for all wire thicknesses.

10.5 CONCLUSIONS

Of the five separators tested, the AAF and MSA units performed satisfactorily in that they removeddat least 99% of the entrained water in the 2.5 - 10 micron range and probably in the 1 - 2.5 micron range, but this was not measurable. Their pressure drop was less than 1 in. WC at rated flows of 1140 scfm for the AAF and 1600 scfm for the MSA separator. -The Farr and Monsanto separators were approximately 90 and 85% efficient, respectively, in the 2.5 - 10 micron range based only on the water collected in the downstream sump. The York separator allowed reentrainment of water which resulted in an efficiency of 40% at all particle size ranges and had a pressure drop greater than 1 in. WC at rated flow of 1600 scfm.

11. Special Areas of Study

The contract listed the following nine areas which were to be investigated:

1. Efficiency versus particle size
2. Efficiency versus flow rate
3. Efficiency versus dust loading
4. Efficiency versus pressure drop
5. Pressure drop versus dust loading --
6. Cleanability
7. Air shock resistance versus loading
8. Flooding
9. Corrosion resistance

Following is a discussion of each of these areas:

1. Efficiency versus particle size- This is discussed in detail in Section 10.

2. Efficiency versus flow rate - This is also discussed in detail. in Section 10.

3. Efficiency versus dust loading - The AAF and MSA moisture separators were dust loaded in an existing MSA facility similar to that used at NBS and described in a paper by R. S. Dill entitled "A Test Method for Air Filters" - ASHVE Transactions, vol. 44, Page 379, 1938. The ETF was not used because there was no provision for adding dust and because dust could adversely affect the operation.

Dust loaded separators were not tested for efficiency in the ETF 'because they could only show a higher efficiency than the 99% reported when clean. Another reason was that the dust was so rapidly removed from the separators by a water spray that the flowmeters in the drains would have been plugged. The fact that so short a time would have been available to collect data either before the dust was washed out or before the drains plugged made this operation impractical.

3. Efficiency versus Pressure drop - This is discussed in Section 10; however, it should be pointed out that the efficiency of the various particle sizes could not be correlated with pressure drop.

5. Pressure drop versus dust loading - An AAF and an MSA moisture separator were dust loaded using NBS dust (8-12 μ) until the pressure drop increased 100% or for a long enough time to establish a trend.

Table 12 summarizes the results of the test and actual data for the AAF separator is shown in Table 13 and for

TABLE 12 - DUST LOADING SUMMARY

Separator	Run Time	Dust Weight (gm) Fed	on Separator	ΔP % Decrease
AAF	505	611	224	13
MSA	216	343	252	100

The MSA-separator showed an increase of 100% in the differential pressure after retaining 252 grams of dust in 216 minutes. The AAF separator differential pressure had increased only 13% after collecting 252 grams of dust in 505 minutes so the test-was terminated. The difference in performance seemed to result from the fact the MSA separator removed the dust in the fibers while the AAF separator removed some- of the dust in the baffles and some in the-fibers but much of the dust passed through and was visible in the downstream air.'

TABLE 13

AAF SEPARATOR DUST LOADING TEST

Time #in	ΔP in. H_2O	Flow cfm	-Feed gm/min	Remarks
0	0.84	1140	1.20	
5	0.86	1140	1.20	Find dust noticeable downstream
15	0.86	0	0	Down 15 min.
45	0.86	1140	1.20	
105	0.86	0	0	Down 35 min.
140	0.86	1140	1.20	
165	0.88	1140	1.20	Fine dust noticeable downstream
180	0.90	1140	1.20	
255	0.90.	0	0	Down 15 min.
270	0.90	1140	1.20	
320	0.90	1140	1.20	307 gm dust fed in 255 min.
0	0.90	1140	1.22	Down 17 hrs 25 min.
15	0.90	0	0	Down 15 min.
30	0.95	1140	1.22	
90	0.95	1140	1.22	Fine dust noticeable downstream
180	0.95	0	0	Down 65 min.
245	0.95	1140	1.22	
330	0.95	1140	1.22	304 gms fed in 250 min.

Total run time	505 min.
Total dust fed	611 gms
Weight gain of MS	224 gms

TABLE 14

MSA SEPARATOR DUST LOADING TEST

Time Min.	ΔP in. H20	Flow cu ft/min.	Peed gm/min.	Remarks
0	0.90	1600	1.72	
5	0.93	1600	1.72	
12	0.96	3	0	Down for.5 min. Small amount of dust downstream
17	0.96	3.600	1.72	
37	1.04	1600	1.72	
47	1.09	-1600	1.72	
56	1.25	1600	1.72	88-p of dust fed in 51 min.
0	1.12	1600	1.61	Down 21 hrs
10	1.17	0	0	Down 10 mix. Dust noticeable in duct downstream
20	1.22	1600	1.61	
35	'1.26	1600	1.61	
50	1.30	1600	1.61	
60	1.32	0	0	Down 40 min.
100	-1.32	1600	-1.61	
110	1.35	0.	0	Down 20 min. 97 gm dust fed in 60 min.
130	1.35	1600	1.56	
135	1.37	1600	1.56	
145	1.42	1600	1.56	
160	1.50	1600	1.56	
180	1.56	1600	1.56	
195	1.61	0	0	Down 45 min.
240	1.61	1600	1.56	
255	1.70	1600	1.56	
270	1.80	1600	1.56	158 gpm fed in 105 min.

Total Run Time 216 min.
Total Dust Fed 343.0 gms
Weight Gain of Moisture Separator 252.0 gms

6. Cleanability - Handling the separators after dust loading was a problem because the dust was-dislodged by the slightest bump. Some dust was lost when the separators were removed from the test apparatus and some was lost in handling but this was held to a minimum by enclosing them in plastic.

The separators were cleaned by tapping the housings with a wood stick and by washing with a spray of water. In both cases the dust was collected on a plastic sheet but some was lost in the air and in the water. The MSA separator was washed with the mesh in place but the mesh was removed from the AAF separator and washed separately. It is recommended that if -an AAF separator. is ever loaded with dust that the mesh be replaced because after-washing there could be areas of by-pass. This should cause no problem because the mesh is easily' removed and replaced. The following table gives an indication of the cleanability of the separators.

TABLE 15 - CLEANABILITY OF SEPARATORS

Separator	Wt of Dust Loaded (gms)	Dust Removed Shaking (gms)	Dust Removed Washing (gms)	Dust Unaccounted For (gms)
AAF	224	154	48	22
MSA	252	181	42	29

Since the dust was so easily removed from the separators by the methods used and since a serious operational problem would have existed if the loaded separators had been installed in the Environmental Test System no further cleaning was done.

7. Air shock resistance versus loading - Each separator was shocked several times at various water loadings by reducing the flow to zero and then increasing it as rapidly as possible to the rated flow for the separator. This was also done to the separators which were dust loaded. While this did not constitute a severe shock, 'it was all that was possible in the existing equipment.

None of the separators showed any deterioration to these shocks and based on their construction, it appeared that they would withstand a force many times greater.

8. Flooding - As discussed in Section 10, none of the separators except possibly one demonstrated. any tendency to flood. The water input was limited by the maximum amount available from the sprays but this was well above what would be expected in operation.

9. Corrosion resistance - No testing was necessary because the separa-tors are made of stainless steel and. fiberglass and both of these materials are resistant to most chemicals likely to be encountered. For special applications any metal could be substituted for the stainless steel and Teflon or Nylon fibers could replace the fiber glass and if the application warrants, stainless steel mats could-be used in place of the fibers.

GLOSSARY

AAF	American Air Filter Company
AEC	(United States) Atomic Energy Commission
Ambient	Atmospheric pressure and temperature
ASME	American Society of Mechanical' Engineers
Atmos	Atmospheric
cu ft	Cubic feet
CFM	Cubic feet per minute.
CUB	calibrated Upright Blower System
CUM	Cubic meter --
DOP	DiOctyl Phthalate
ETF	Environmental Test Facility
F	(degrees) Fahrenheit, Filter
ft	feet
ft^2	square feet
ft^3	cubic feet
FPM	Feet per minute
Ga	Gage
gm	grams
HEPA	High Efficiency Particulate Air (Filter)
hr(s)	hour(s)
Hx	Beat exchanger

GLOSSARY (continued)

I.D.	Inside diameter
in.	inches
$in.^2$	square inches
lbs	pounds
L (I.R.C)	Level, I - Indicator R - Recorder C - Controller
M^3	cubic meters
max	maximum
min	minimum
mm	millimeters
MND	Mean Numerical Diameter
MSA	Mine Safety Appliances Company
MVD	Median Volume Diameter
NPS	Nominal pipe size
OA	overall
OD	outside diameter
P (I,R,C)	Pressure, I - Indicator R - Recorder, Regulator C - Controller
psi (g,a)	pounds per square inch, g - gage a - absolute
PWR	Pressurized Water Reactor
rads	Radiation absorbed dosage (1 rad = 100 ergs/gm)
RH	Relative Humidity

GLOSSARY (continued)

SCFM	Standard cubic feet per minute
SF	square feet
SG	sight glass
SMD	Sauter Mean Diameter
T (I,R,C)	Temperature, I - Indicator R - Recorder C - Controller
WC	Water Column
W - H - D	Width - Height - Depth (Diameter)
μ	microns, 10^{-6} meters, 10^{-3} mm, 25.4 u/0.001 in,
Δ	differential
>	greater than
<	less than
∿	approximately
%	percent

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APPENDIX

This-section contains-- detailed information on the five separators, A description of each separator, the method of installation and the test results are given. Included in the test results are visual observations,.' results of impactor tests and HEPA monitoring, The results of each separator performance are summarized and conclusions made.

A. MONSANTO BAFFLE-TYPE SEPARATOR

B. FARR TYPE 68-44MZH SEPARATOR

C. YORK TYPE 321 Sk SEPARATOR

D. AAF TYPE T SEPARATOR

E. MSA TYPE G SEPARATOR

A. MONSANTO-BAFFLE-TYPE SEPARATOR

Monsanto's high efficiency packed-fiber separators are used for acid plant effluent treatment.3 Cased on MSA survey results[2], none of these separators were selected for test evaluation in this program because of their higher pressure-drop characteristics (2-10 in. WC) at lower flow velocities (5-250 fpm); and since availability was on a rental basis only, the modification required for this program was prohibited.

However, Monsanto furnished, unsolicited, two of their standard baffle-type separators without further identification or technical detail, from the Mound Laboratory, Miamisburg, Ohio. MSA did request data on the separators but none were received. Although there was no information available that'this basic separator would be adequate for fine particle separation service, MSA decided to proceed with testing. Description and test performance are presented in the following subsections.

A.1 DESCRIPTION

Appearance:	See Figures 27 and 28 for photographs.
Type:	Typical baffle design. 2-stage vane and hook. 20 baffles/separator.
Size:	24 in. W x 24 in. H x 2 in. D, overall case. 3/8 in, wide flanges, all. around outlet face, omitted on lower side of inlet face. 3.76 sq ft minimum face area.
Materials:	All stainless steel; 16 gage nominal thickness.
Assembly:	All welded
Weight:	25 3/4 lbs
Rating:-	Not specified. 1800 cfm used, giving 480 fpm based on higher flow rates normally used for baffle-type separators.

A.2 ETF INSTALLATION

The Monsanto Separator was installed with a gasket seal -- on the upstream face and downstream drainage was provided. This resulted in a 1/2 in. flange which retained water within the inches of downstream duct for. collection of separated entrainment for measurement. For increased visibility at ambient operation, the 7-inch long Plexiglass section was inserted into the ETF; any water collecting in this section would have to reach a depth of 1/4 in. before overflowing into the water sump for measurement. This was followed by-the monitoring HEPA filter with its inlet face 12 inches downstream from the outlet face of the separator,

A.3 TEST RESULTS

The Monsanto separator, as described and installed, was operated at ambient conditions in accord with the general test plan of Section 4. Summarized data are presented in Tables Al and A2 and in Figures Al, A2 and A3, with additional observations as follows:

A, 3.1 ETF Test Observations

A 1000 cfm flow of dry air at ambient pressure and temperature was used to establish this-pressure drop at rated HEPA flow. It was then increased tc 1800 cfm for pressure-loss readings at the rated separator flow arid held there for the balance of testing when entrained water was added to the flow.

Entrainment was initiated at a low rate (54 lbs/hr) of large particle size (100 micron MVD) using one bank of eight TX-I. nozzles operating at 40 psi. Water became immediately visible downstream of the separator. Droplets formed on-the lower one-third of the outlet edges of the baffles. Some drained into the bottom of the separator case until it overflowed the 5/16 in. high lower outiet flance and dropped into the separated water collection sump. Other drops were reentrained by the air flow directly from the baffles and occasionally from the lower flanqe overflow, Drop out occurred primarily in -the 7-inch long Plexiglass section beginning 6 inches from the downstream face of the separator. Measurements were made by weighing collected amounts of water from each sump over a period of time since insufficient head -was available for operation of the flowmeters.

Entrainment loading was -increased. in steps by turning on additional banks of TX-1 nozzles until-all 108 nozzles were operating at 40 psi for 100 micron MVD particle size. These gave an entrainment removal rate of 613 lbs/hr, corresponding to 5.7 lbs/1000 cu ft. Water penetrating beyond the separator-removal sump did not appear to increase with increased loading. Maximum loading of 717 lbs/hr, 6.6 lbs/1000 cu ft, was achieved by increasing the TX-1 nozzles pressure to 80 psi which also increased particle size to approximately 70 micron MVD. A series of photographs were taken to illustrate test installation and performance observations. The stream temperature was held constant by periodic use of cooling water in the heat exchanger.

TABLE A1 - MONSANTO SEPARATOR PERFORMANCE DATA

ETF Test - 18
October 28, 1970
Atmospheric Pressure
RH: 94% Start, 100% @ 14:30

Time	Temperatures °F							Pressures			Spray	Flow Rates		
	HEPA		Separator		Heat Exchanger		Spray Water	Spray Water psig	Pressure Drop Inches WC		size µ MVD	Gas Stream CFM	Separator Removal lbs/hr	Separator Penetration
	Out	In	Out	In	Out	In			HEPA	Separator				
									0.90	0.10		1000		
0823									1.81	0.35		1800	Dry Readings	
0850								40	1.825	0.38	100	1800		
0900								40	1.825	0.38	100	1800	54.5	
0930							91	40	1.825	0.38	100	1800	55	Water visibly re-
1020							89.5	40	1.87	0.38	100	1800	53	entrained >6" down
1100	107.5	105.5	105.5	104	109	111.5	106	40	1.87	0.38	100	1800	110.5	stream of the sepa-
1130	108	106	106	104	109.5	112	108	40	1.87	0.38	100	1800	113	rator but not in
1200	107	105.5	105.5	103	109	112	109	40	1.88	0.38	100	1800	113	enough volume for
1300	107	105	105	103	108.5	112	112	40	1.88	0.38	100	1800	176	measurement
1330	105	103.5	103.5	101	107.5	111.5	90	40	1.87	0.39	100	1800	305	
1358	95.5	94	94	92	93	104	82	40	1.86	0.41	100	1800	613	
1430	93	91	91	91	94	101	82	80	1.85	0.42	70+10	1800	717	[illegible]
1500	90.5	89	89	89	92	91	78	80	1.94	0.42	70+10	1800	717	[illegible]
1530	98	95.5	95.5	97	97	97			1.97	0.38	10	1800	3.66	tration r[illegible]
1607	97	95.5	95.5	97	97	97			1.97	0.38	10	1800	3.66	the HEPA
1611														

7.4 hrs Exposure Time

ITEM	Before Test						After Test					
	0.3 µ DOP			0.6 µ DOP			0.3 µ DOP			0.6 µ DOP		
	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM
SEPARATOR	100	0.09	1000	100	0.12	1125						
				98	0.32	1800						
				99	0.48	2250						
HEPA-9	0.001	0.90	1000				0.001	0.90	1000			

TABLE A2 - MONSANTO SEPARATOR
AVERAGE CONDITIONS FOR ETF TEST-18

Description	Value
HEPA Outlet Temperature, F	100.85
HEPA Inlet Temperature, F	99.05
Separator Outlet Temperature, F	99.05
Separator Inlet Temperature, F	98.1
Spray Water Temperature, F	94.75
Heat-Exchanger Outlet Temperature, F	101.65
Heat Exchanger Inlet Temperature; F	104.9
Syster Pressure* psig	Atmospheric
HEPA Pressure Drop, inches WC	1.88
Separator Pressure Drop., inches WC	-0.38
System Flowrate, CFM	1800
Separated Entrainment:	
100 μ MVD, lbs/hr	to 613
70 + LO μ MVD, lbs/hr	717
10 μ MVD, lbs/hr	3.66
Penetrated Entrainment (Dropout): -	
100 μ MVD, lbs/hr	Accumulating
70 + 10 μ MVD, lbs/hr	0.37 + mist
10 μ MVD, lbs/hr	0.37 + mist

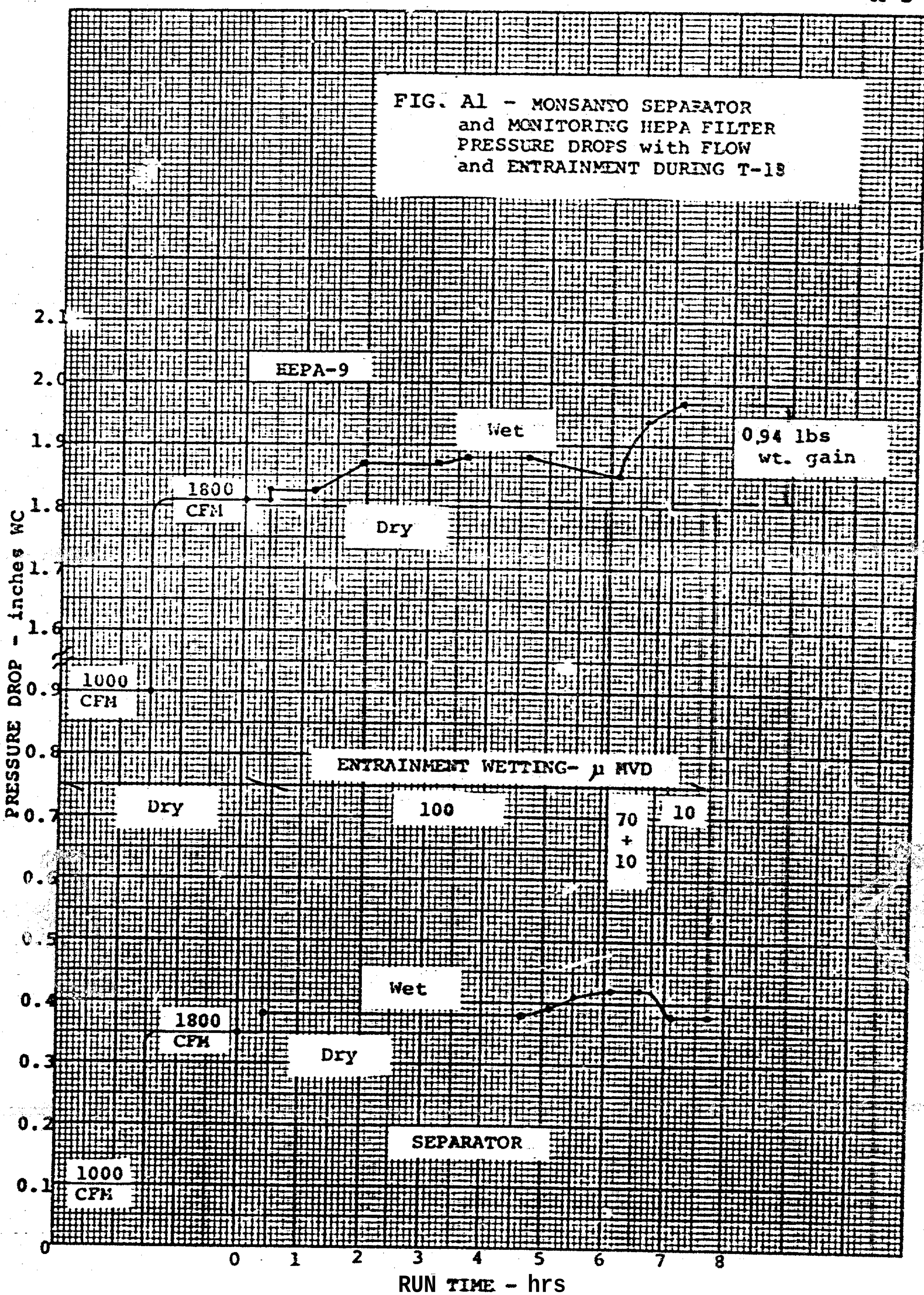
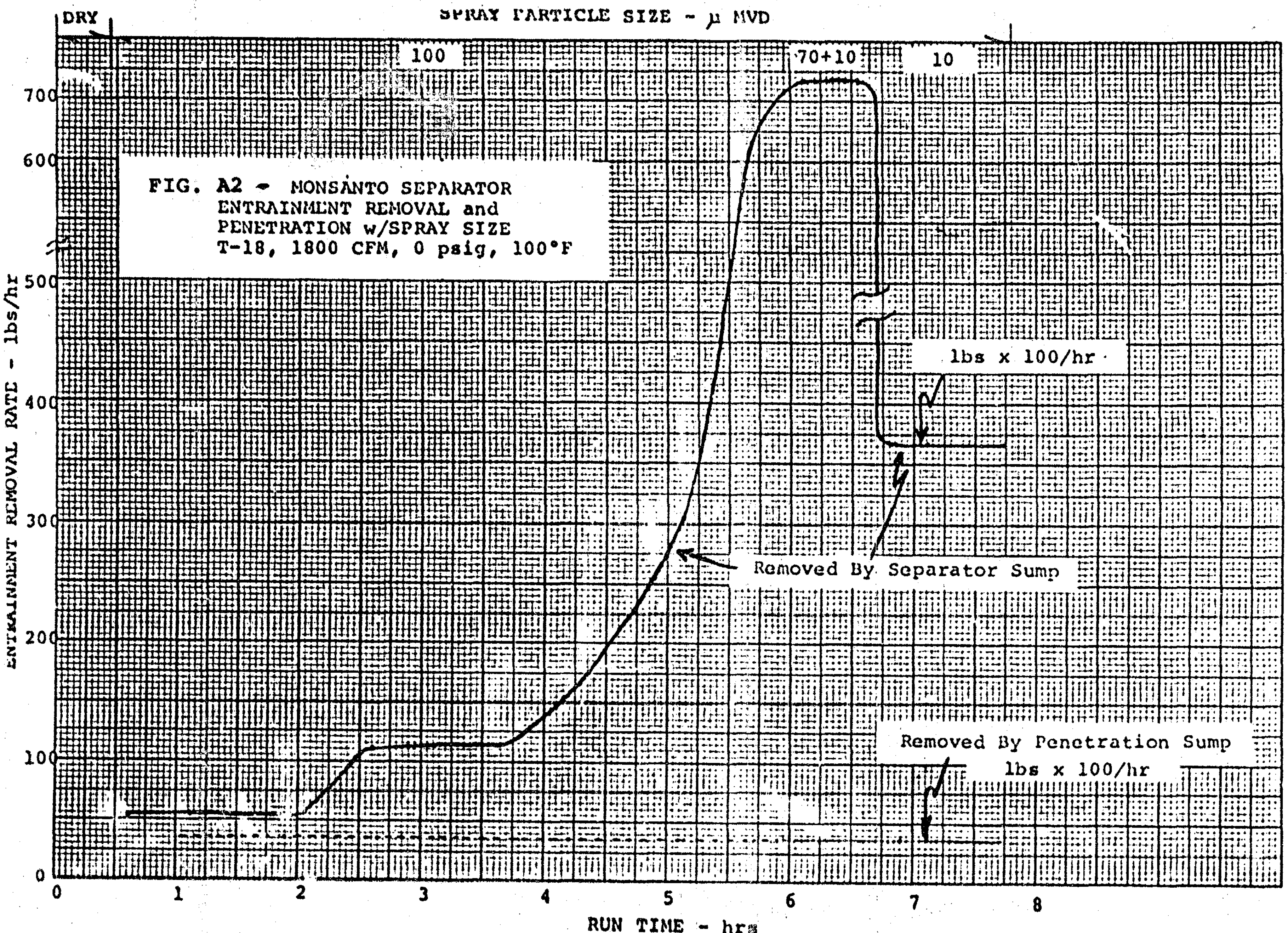
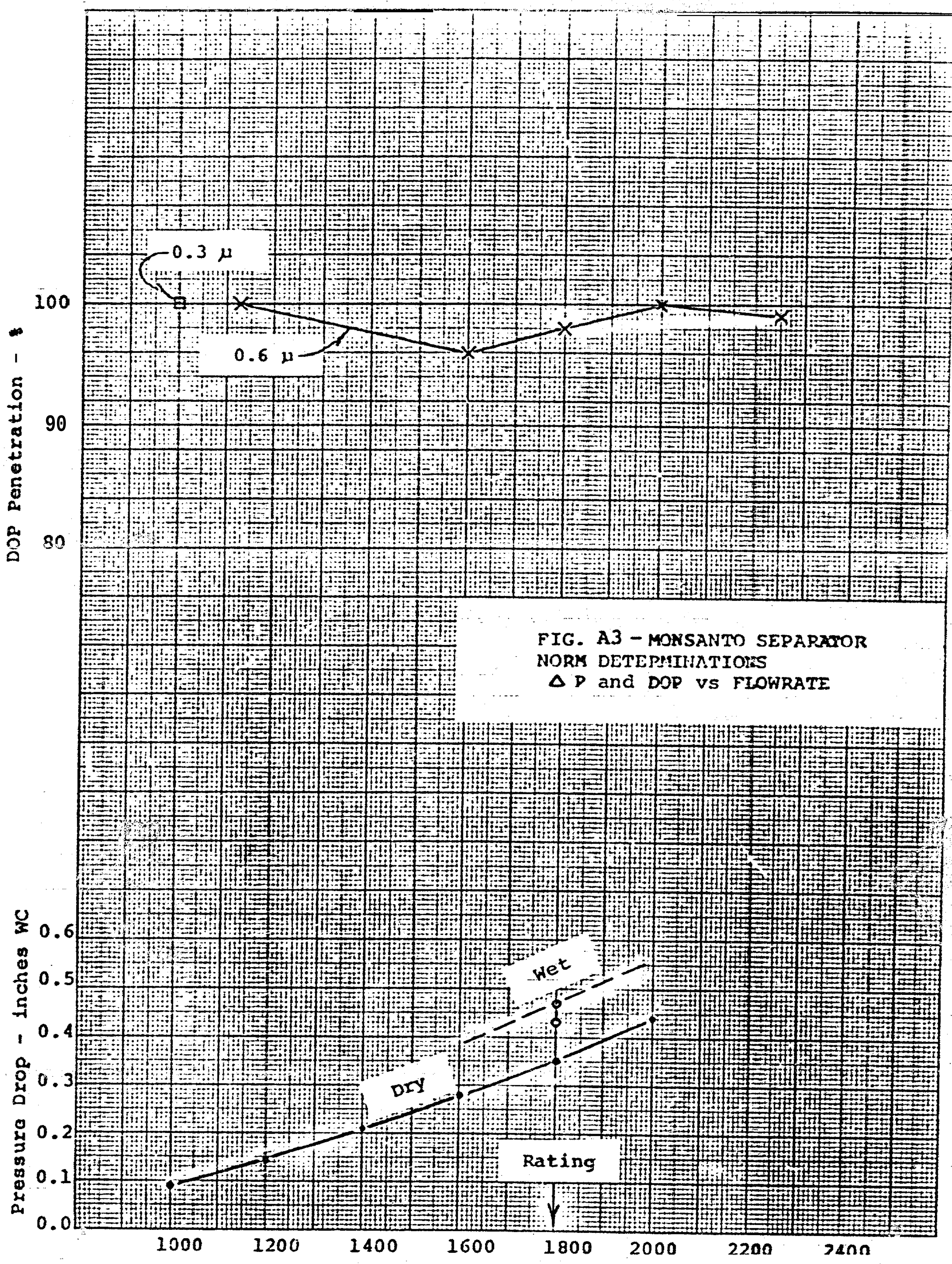


FIG. A1 - MONSANTO SEPARATOR and MONITORING HEPA FILTER PRESSURE DROPS with FLOW and ENTRAINMENT DURING T-18
HEPA-9
Wet
0.94 lbs wt. gain
1800 CFM
Dry
1000 CFM
ENTRAINMENT WETTING- µ MVD
Dry
100
70 + 10
10
Wet
1800 CFM
Dry
SEPARATOR
1000 CFM
PRESSURE DROP - inches WC
RUN TIME - hrs
0
1
2
3
4
5
6
7
8


SPRAY PARTICLE SIZE - μ MVD
DRY
100
70+10
10
FIG. A2 - MONSANTO SEPARATOR
ENTRAINMENT REMOVAL and
PENETRATION w/SPRAY SIZE
T-18, 1800 CFM, 0 psig, 100°F
lbs x 100/hr
Removed By Separator Sump
Removed By Penetration Sump
lbs x 100/hr
ENTRAINMENT REMOVAL RATE - lbs/hr
0
100
200
300
400
500
600
700
RUN TIME - hrs
0
1
2
3
4
5
6
7
8



0.3 µ
0.6 µ
100
90
80
DOP Penetration - %
FIG. A3 - MONSANTO SEPARATOR
NORM DETERMINATIONS
Δ P and DOP vs FLOWRATE
Wet
Dry
Rating
Pressure Drop - inches WC
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000
2200
2400

A.3.2 Impactor Results

Impactor sampling for efficiency measurements of the 1-10 micron particle size entrainment fraction was performed during this ETF run with results as reported in Table A3. These results are very-similar to those obtained when testing the impactor at ambient conditions. The concentration of particles in both the challenge stream and the penetration stream appear very low. Visual observation indicated a dense fog at the inlet to the separator and a downstream fog of about 25% of the inlet. Impactor measurements indicated an inlet concentration slightly below the visible range and an outlet concentration of possibly a factor of a hundred below.

Converting the 0.37 lbs/hr removed from the downstream sump to lbs/cu ft gives 3.43 x 10^{-6}. Comparing this to the measured penetration in Table A3 shows that the measurement is a factor of about 100 less. Further conversion to 54.9 mg/cu M and referring-to Figure 25 shows that this is in the visible *range;* The efficiency of the Monsanto Separator in the small particle range tested was 85.2% as compared to the 99+% considered acceptable..

A.3.3 Summary of HEPA Monitoring

HEPA pressure drop increased with large (100 micron MVD) entrainment duty to 1.87 ± 0.01 in. WC.-- a 3.3% increase from the dry value at 1800 cfm. HEPA pressure drop did not vary noticeably with the magnitude of 100 micron MVD entrainment loading on. the separator. HEPA pressure drop did increase measurably with the introduction of fine (10 micron MVD) entrainment into the inlet stream, reaching 1.97 in.WC -- a 5.3% gain from the 1.87 in. WC level with 100 micron MVD separator duty and an 8.85% total gain from the 1.81 in. WC dry value at 1800 cfm. HEPA water pick-up during this run was measured as 15 ounces by weight difference: This wao evaporated during final pressure drop-DOP measurements following the- run.

A.3.4 Summary of Separator-Performance

Separator pressure drop of 0.35 in.. WC at 1800 cfm ambient air increased less than 10% with either 10 or 100 micron MVD particles *over* a wide range of-loadings from 4 to 200 lbs/hr. It increased 20%, reaching 0.42 in. WC at maximum loading of 721 lbs/hr. The 70-100 micron MVD efficiency remained high (>99%) throughout the test, indicating flooding capacity was not approached, The 10 micron MVD efficiency was very poor (about 85%), based on the sum of water removed through the normal drain and the rather constant reentrainment dropout portion collected, as described, in the Plexiglass section downstream of the normal drain.

TABLE A3 - FINE PARTICLE EFFICIENCY DATA FOR MONSANTO BAFFLE-TYPE SEPARATOR

ETF Test 18

1800 CFM Air
3.6 lb/hr Entrainment Removal Rate
0 psig
104 F
100% Relative Humidity

μ dia	Measured Challenge Stream lb/cu ft	Measured Penetration lb/cu ft	Apparent Penetration %	Apparent Efficiency %	Actual Efficiency %
2.5	1.7×10^{-9}	1.2×10^{-9}	61	39	
4.0	13.6×10^{-9}	4.1×10^{-9}	30	70	
5.6	640×10^{-9}	14.5×10^{-9}	2.2	97.2	
7.2	151×10^{-9}	11.6×10^{-9}	7.5	99.2	
8.8	179×10^{-9}	0.6×10^{-9}	0.31	96.7	
Total	985.3×10^{-9}	32.0×10^{-9}		96.8	82.5

A. 4 CONCLUSIONS

The Monsanto Baffle-type Separator is not acceptable for service in the l-10 micron range. Where appreciable quantities of fine (l-10 micron MVD) entrainment-must be removed, the removal efficiency would be 85% or lower,

Based on the ambient testing and the lack of'technical data from the manufacturer -- including any restrictions -- it was concluded that no elevated-temperature testing would be done on this separator.

B. FARR TYPE 68-44MZH SEPARATOR

Farr proposed to furnish several types and sizes of filters for MSA evaluation in this program -- filters which are not normally recommended for 1-10 micron service. Separators of standard protected carbon-steel construction were purchased for testing.

Description and test performance results are presented in the following subsections.

B.1 DESCRIPTION

Appearance: See Figures 29 and 30 for photographs.

Type: 68-44MZH, specially arranged wire-cloth media.
3-42353-A Farr outline drawing,
B-42354-2 Farr manufacturing reference in carbon steel.
(B-42355-2 Farr manufacturing reference in stainless steel)

Size: 23 1/2 in. W x 23 1/2 in. H x 3 15/16 in. D, overall case.
5/8 in. wide flanges all around both faces.
2 handles for installing on one face.
3/8 ø x 6 holes/side for drainage,
3.44 sq ft minimum face area.

Materials: Carbon steel, hot-dip galvanized with zinc chromate finish, media and frame (16 Ga).

Assembly: Mechanically interlocking of production-formed components.

Weight: 31.5 lbs

Rating: 860 minimum - 1785 nominal- 2384 maximum cfm

Figure B1 - efficiency and ΔP for dust. None available for entrained liquids,

B.2 ETF INSTALLATION

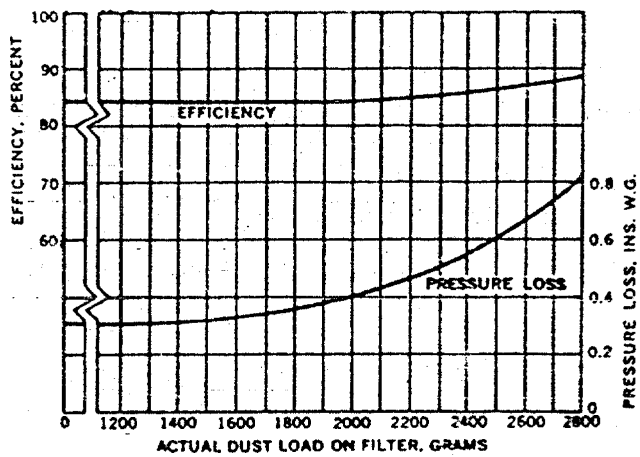
The Farr Separator was installed in the ETF with general arrangement as indicated in Figure 1. The upstream face was sealed.

(MSAR) **FIG. B1** - FARR SEPARATOR

T-200-13A

RATED PERFORMANCE CHARACTERISTICS

4" panel filter' type **44-68**



LOADING

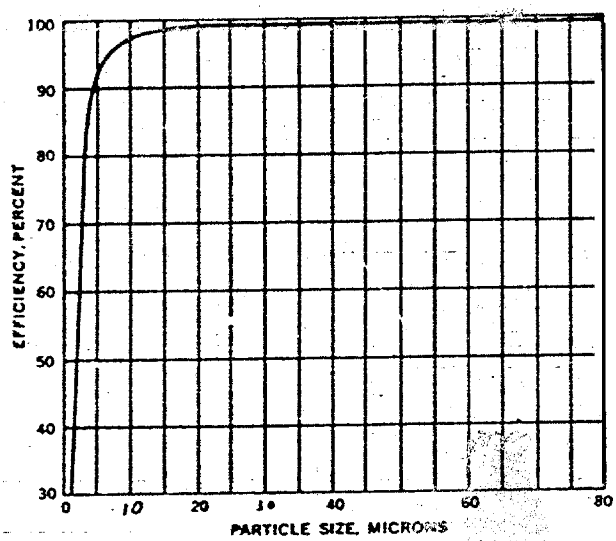
AIR Flow: 319 **FPM** (1200 CFM PER 20" x 20" PANEL)

DUST FEED: 20 GMS PER HOUR (0.278 GMS./1000 CF.)

TEST DUST: STANDARDIZED FINE AIR CLEANER TEST DUST NO. 1543094. SPECIFIC GRAVITY 2.54.

PARTICLE SIZE RANGE MICRONS:	0-5	5-10	10-20	20-40	40-80
% BY WEIGHT ± 3 %	39	18	16	18	9

CHEMICAL ANALYSIS:	METAL OXIDES	ALKALIES	IGNITION LOSS
% BY WEIGHT	92.71	4.61	2.68



PARTICLE SIZE

AIR FLOW: 519 FPM (1200 CFM PER 20" X 20' PANEL)

OUST FEED: 20 GMS. PER HOUR TO 20' X 20" PANEL (278 GMS/1000 CF)

TEST DUST: STANDARDIZED FINE AIR CLEANER TEST DUST #1543094 CLASSIFIED INTO THE FOLLOWING MICRON PARTICLE SIZE RANGES: 0.5. 5-10, 10-20, 20-40 AND 40-80.

EFFICIENCY IS READ AT MEAN PARTICLE SIZE Of EACH PARTICLE SIZE RANGE.

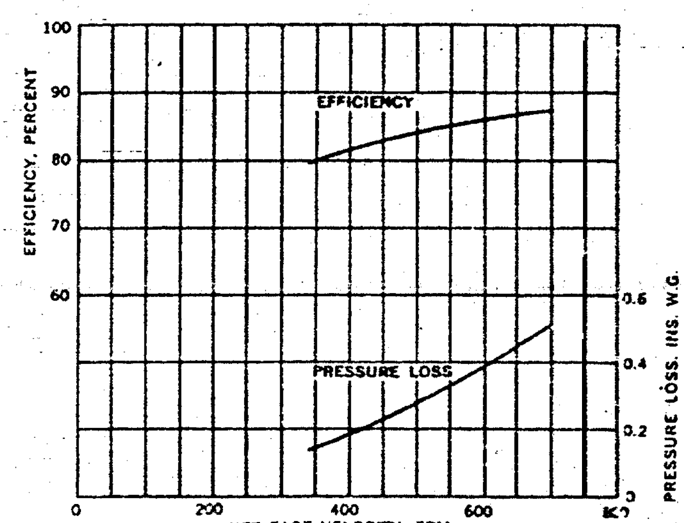
VELOCITY

NET FACE VELOCITY IS COMPUTED OVER THE MEDIA AREA INSIDE THE FLANGES OF THE FRAME.

EFFICIENCIES SHOWN ARE FOR A CLEAN OILED FILTER.

DUST FEED RATE: 20 GMS PER HOUR TO A 20" X 20" PANEL.

TEST DUST: STANDARDIZED FINE AIR CLEANER TEST DUST #1543094. SPECIFIC GRAVITY 2.54.



were sealed with RTV sealant. The six lower holes were positioned for drainage into the separated water sump which also drained an additional 4 inches of the downstream duct. The 7 in. long Plexiglass duct section was fitted with a drain provision before installation 4 in. downstream of the separator outlet face. The monitoring HEPA inlet face was again located at the end of the final penetrated water sump, an additional 12 in. downstream, and a total of 23 in. from this separator outlet face;-

B.3 TEST RESULTS

The Farr Separator, as described and installed, was operated at ambient conditions in accord with the general test plan of Section 4. Summarized data are presented in Tables B1 and B2 and in Figures B2, B3 and B4, with additional observations as follows:

B-3.1 ETF Test Observations

Circulating air flow at ambient pressure and temperature was started at 1000 cfm to obtain a dsta profile at rated HEPA flow. It was then increased to 1800. cfm. for the rated separator flow profile and held at that flow for the balance of testing with entrainment conditions. Cooling water flow for the heat exchanger was adjusted to keep the circulating gas stream temperature from escalating.

Entrainment was initiated at a low rate (51 lbs/hr) of large particle size 9 100 micron MVD) using one bank of eight TX-1 nozzles operating at 40 psi. Entrainment was completely removed within the separator case with no measurable or visible sign of penetration beyond the outlet face of the separator. Entrainment loading was increased in steps to the-maximum value of 566 lbs/hr obtainable with all TX-1 nozzles on at 40 psi; no penetration was observed. Spray pressure was then increased to 80 psi on the TX-1 nozzles, decreasing the particle size 70 micron MVD and further increasing loading to >700 lbs/hr without sign of penetration.

Fine particle component of entrainment was then increased by adding the output of al.1 1A nozzles. Maximum combined (10 micron + 70 micron) loading reached 738 lbs/hr. Penetration became immediately visible when the 10 micron fraction was added. Wisps of fog penetrated the separator and entered the downstream HEPA filter. Partial agglomeration of some particles was visible at the separator outlet which resulted in a low rate of reentraiument. Most of these particles dropped into the 4 in. long exposed section of the separator drain sump and into the following 7 in. long Plexiglass section.

TABLE B1 - FARR SEPARATOR PERFORMANCE DATA

ETF Test - 19
November 2, 1970
Atmospheric Pressure
RH: 96% start, 100% @ 16:40

Time	Temperature °F HEPA Out	HEPA In	Separator Out	Separator In	Heat Exchanger Out	Heat Exchanger In	Spray Water	Pressures Spray Water psig	Pressure Drop Inches WG HEPA	Pressure Drop Inches WG Separator	Spray size μ MVD	Flow Rates Gas Stream CFM	Sep Removal lbs/hr	Re-entrainment Dropout lbs/hr
									0.90	0.09		1000	Dry	Readings
0922									1.77	0.20		1800		
0930	81	80	80	81	82	81	77	40	1.77	.	100	1800		
1005	92	88.5	88.5	89	95	93	80	40	1.78	0.30	100	1800	51	
1032	97.5	95.5	95.5	96.5	102.5	100.5	85	40	1.78	0.30	100	1800	75	
1103	104.75	103	103	104	109.5	107.5	106.5	40	1.825	0.30	100	1800	114	No
												1800	172	visible
1130	108	106.5	106.5	106.5	113	111.5	109.5	40	1.88	0.32	100	1800	325	penetration
1200	102	100	100	100	103	108	89	40	1.90	0.34	100	1800	567	
1250	90.5	87	87	88.5	91.5	97	73	80	1.85	0.35	70	1800	697	
1300	90	87.5	87.5	78	91.5	91	76	80	1.87	0.35	70+10	1800		Immediate visible
1350	87	85	85	86	88.5	81	74	80	1.89	0.35	70+10	1800	723	penetration of mist
1438	86.5	84	84	85	87.5	87	74	80	1.925	0.35	70+10	1800	738	reaching HEPA
1500	94	92.5	92.5	94	95.5	94			1.94	0.33	10	1800		
1530	100.5	99	99	100.5	102.5	100.5			1.98	0.30	10	1800	3.4	
1600	106	104	104	106.5	106.5	105			1.99	0.30	10	1800	2.9	
1647	110	108.5	108.5	109.5	111.5	109			2.02	0.30	10	1800	2.9	0.29
7.3 hr	Exposure Time													

ITEM	Before Test 0.3 μ DOP Pene %	ΔP in.WC	Flow CFM	Before Test 0.6 μ DOP Pene %	ΔP in.WC	Flow CFM	After Test 0.3 μ DOP Pene %	ΔP in.WC	Flow CFM	After Test 0.6 μ DOP Pene %	ΔP in.WC	Flow CFM
Separator	100	0.09	1000	99	0.12	1116						
				99	0.27	1785						
				100	0.40	2231						
HEPA-46	0.001	0.90	1000				0.001	0.88	1000			

TABLE B2 - FARR SEPARATOR
AVERAGE CONDITIONS FOR ETF TEST-19

Item	Description	Value
1	HEPA Outlet Temperature, F	96.43
2	HEPA Inlet Temperature, F	94.36
3	Separator Outlet Temperature, F	94.36
4	Separator Inlet Temperature, F	95.29
5	Spray Water Temperature, F	84.91
6	Heat Exchanger Outlet Temperature, F	98.58
7	Heat Exchanger Inlet Temperature, F	98.22
8	System Pressure, psig	Atmospheric
9	HEPA Pressure Drop, inches WC	1.81
10	Separator Pressure Drop, inches WC	0.314
11	System Flowrate, CFM	1800
12	Separated Entrainment:	
	100 u MVD, lbs/hr	to 566
	70 + 10 u MVD, lbs/hr	to 738
	10 u MVD, lbs/hr	2.9
13	Penetrated Entrainment (Dropout):	
	100 u MVD, lbs/hr	0
	70 + 10 u MVD, lbs/hr	0.29 + fog
	10 u MVD, lbs/hr	0.29 + fog

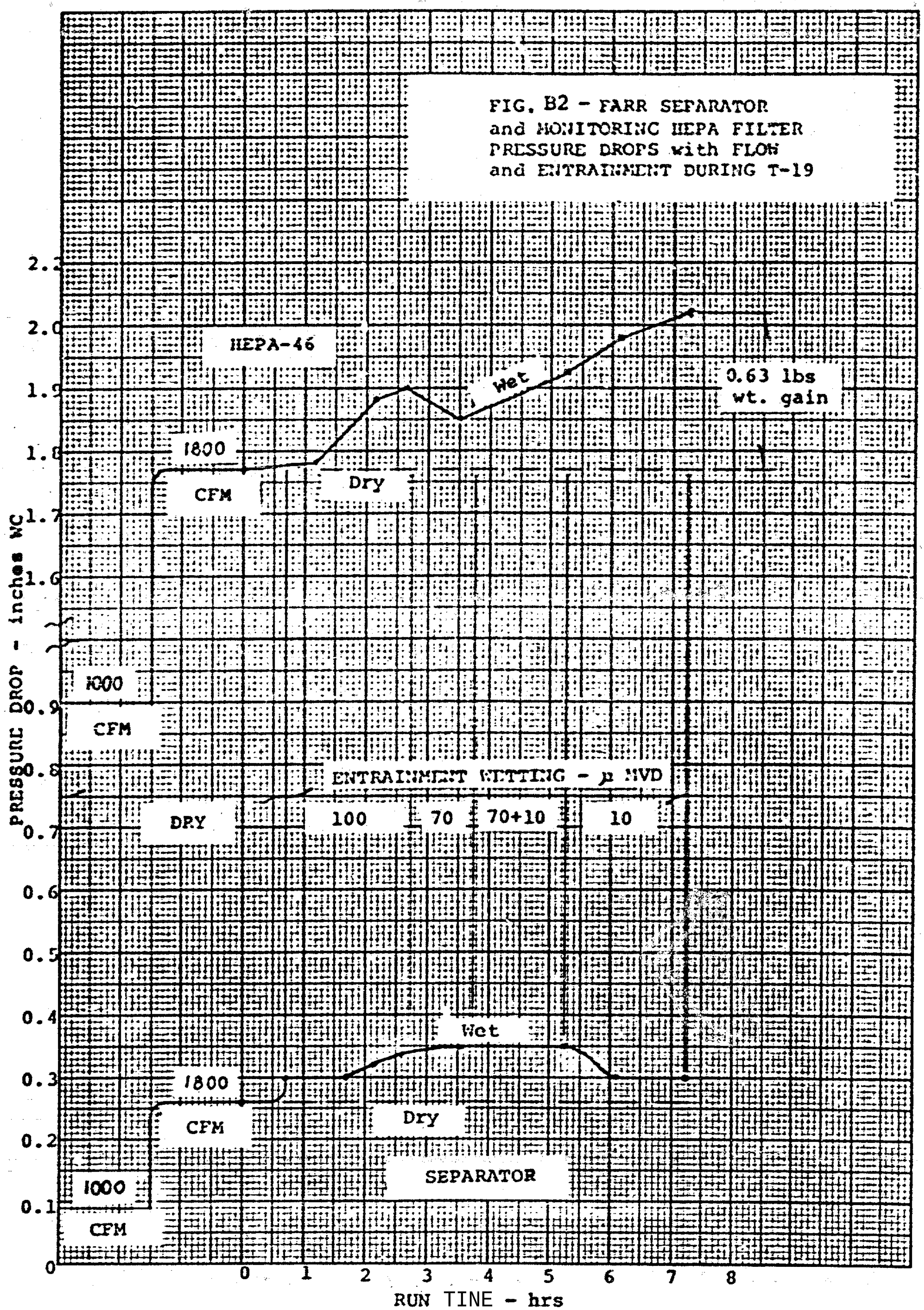
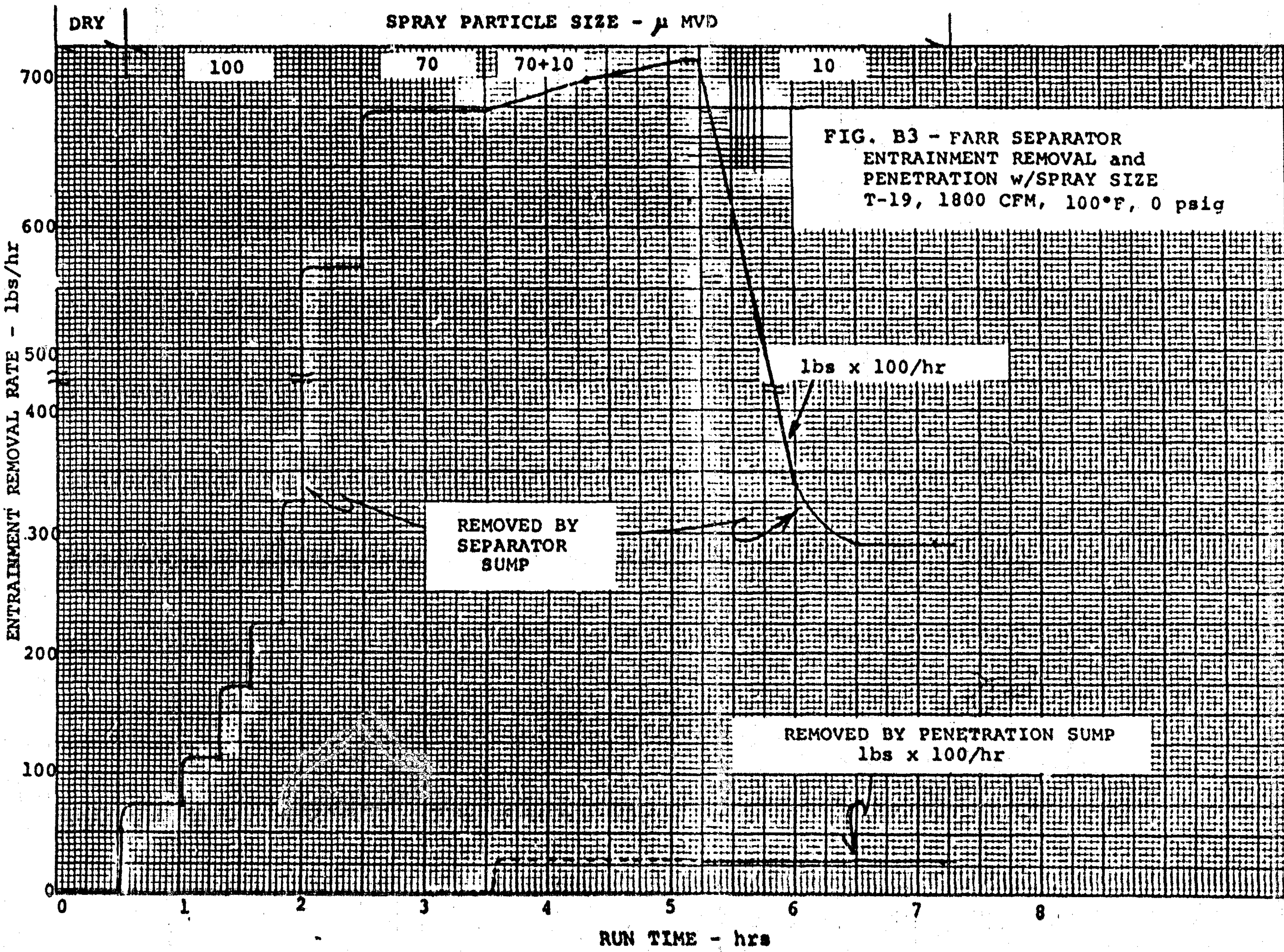


FIG. B2 - FARR SEPARATOR
and MONITORING HEPA FILTER
PRESSURE DROPS with FLOW
and ENTRAINMENT DURING T-19
HEPA-46
1800
CFM
Dry
Wet
0.63 lbs
wt. gain
1000
CFM
ENTRAINMENT WETTING - μ MVD
DRY
100
70
70+10
10
Wet
1800
CFM
Dry
SEPARATOR
1000
CFM
PRESSURE DROP - inches WC
RUN TIME - hrs
0
1
2
3
4
5
6
7
8
2.2
2.0
1.9
1.8
1.7
1.6
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


SPRAY PARTICLE SIZE - μ MVD
DRY
100
70
70+10
10
FIG. B3 - FARR SEPARATOR
ENTRAINMENT REMOVAL and
PENETRATION w/SPRAY SIZE
T-19, 1800 CFM, 100°F, 0 psig
lbs x 100/hr
REMOVED BY
SEPARATOR
SUMP
REMOVED BY PENETRATION SUMP
lbs x 100/hr
ENTRAINMENT REMOVAL RATE - lbs/hr
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
7
8
RUN TIME - hrs

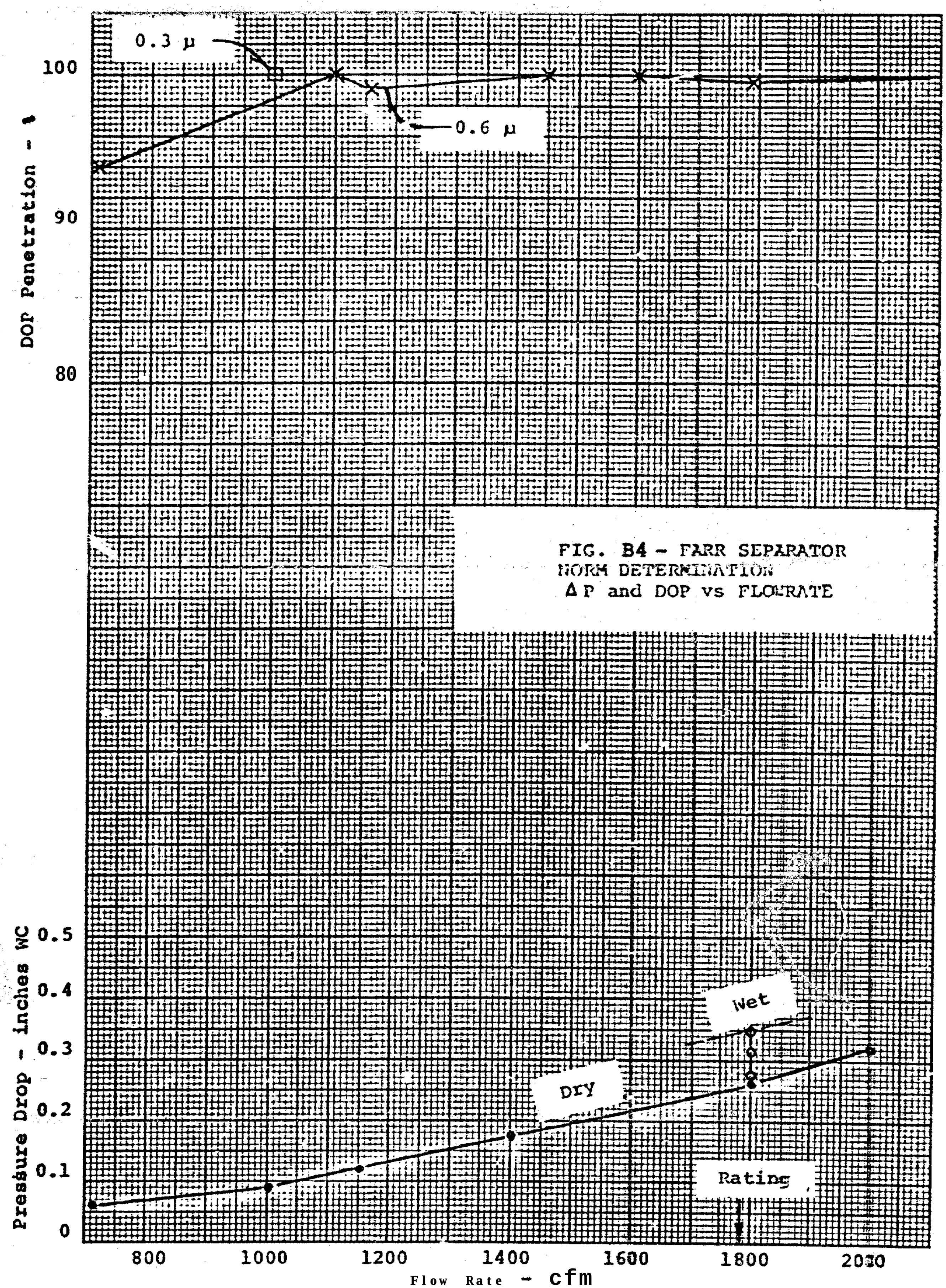


FIG. B4 - FARR SEPARATOR
NORM DETERMINATION
Δ P and DOP vs FLOWRATE

Fine particle performance was further studied by turning off the 100 micron MVD nozzles, leaving on only the 10 micron MVD nozzles for the balance of the test. Penetration continued with wisps of fog to the HEPA and finally enough dropout (0.29 lbs/hr) of agglomerated particles for measurement in the Plexiglass section. A similar amount of reentrainment dropped out into the 4 in. exposed section of the separator drain sump which was measured as combined separator entrainment removal water. only-a trace of reentrainment dropped into the final 12 in. long penetration sump area preceding the HEPA. ETF entrainment removal and penetration dropout measurements were obtained by weighing timed amounts of collected water. A series of photographs were taken to illustrate test installation and visible performance.

B.3.2 Impactor Results

Impactor sampling for efficiency measurements of the 1-10 micron particle size entrainment fraction was performed during this ETF run with results as reported in Table B3. The concentration of particles in both the challenge stream and the penetration stream appear very low. Visual observation indicated a dense fog at the inlet to the separator and a downstream fog of, about 10% of the inlet. Impactor measurements indicated that both the challenge stream and the outlet stream were below the visible range.

Converting the 0.29 lbs/hr removed from the downstream sump to lbs/cu ft gives'2.685 x 10^{-6}. Comparing this to Table B3 shows that the measured penetration is a factor of about 100,000 less. Further conversion to 43.0 mg/cu ft and referring to Figure 25 shows that this is at the lower end of the visible range. The efficiency of the Parr Separator in the small particle range tested was 90% as compared to the 99+% considered acceptable.

B.3.3 Summary of HEPA Monitoring

HEPA pressure drop increased at a fairly regular rate varying somewhat with entrainment particle size and loading (Figure B2). Compared to a dry differential pressure of 1.77 in. WC at 1800 cfm, the final wet differential pressure of 2.02 in, WC represents a 14% increase in differential pressure over this period of entrainment testing. Water picked up by the HEPA during this run was measured at 10 oz by weight difference. This amount was evaporated from the HEPA during final differential pressure-DOP measurements following the run. Separator penetration under these test conditions did not measurably affect HEPA filter integrity,

B.3.4 Summary of Separator Performance

The unusually low separator pressure drop of 0.26 in. WC at 1809 cfm dry increased only 35% to 0.35 in. WC at maximum loading (738 lbs/hr, 6.8 lbs/1000 cu ft) reached in MSA tests. Capacity (flooding) was not reached. Entrainment separation efficiency

TABLE B3 - FINE PARTICLE EFFICIENCY YATA FOR FARR SEPARATOR

ETF Test 19

1785 CFM
2.9 lb/hr Entrainment Removal Rate
0 psig
100 F
100% 'Relative Humidity

dµ i a	Measured Challenge Stream lb/cu ft	Measured enetration lb/cu ft	Apparent Penetration %	Apparent Efficiency %	Actual Efficiency %
2.5	1.4×10^{-9}	6.6×10^{-12}	0.5	99.5	
4.0	11.0 x 10'9	4.6×10^{-12}	0.04	99.6	
5.6	5.3×10^{-9}	6.6×10^{-12}	0.1	99.9	
7.2	12.4×10^{-9}	6.6×10^{-12}	0.05	99.9	
8.8	14.5×10^{-9}	2.0×10^{-12}	0.01		
Total	44.6×10^{-9}	26.4×10^{-12}		99.9	90.0

remained essentially at 100% with LOO-70 micron MVD size entrainment to 700 lbs/hr loading tested, based on no visible mist of reentrainment penetration. Visible mist penetration accompanied by measurable dropout portions decreased removal efficiency to 90% based on 2.9 lbs/hr of 10 micron MVD loading.

B.4 CONCLUSIONS

Removal efficiency with 10 micron MVD entrainment size is 'approximately 90% based on the reentrainment dropout portion. The low impactor results may have been due to non-representative sampling, since visible fog, penetrating the separator, seemed to pass through in irregular wisps or bursts, rather than a continuously uniform penetration as observed for the standard baffle separator. The Farr Separator has the lowest pressure drop tested ((0.4 in. WC) at high velocity (X20 fpm) and high entrainment loading ($\geq$ 6.8 lbs/1000 cu ft of >10 micron size).

C. YORK TYPE 321 SR SEPARATOR

Design and application of the York Type 321 SE Separator was based on specifications and performance data formulated far the Savannah River Reactor Containment Facilities[7]. The separators purchased for these tests were all ordered to these specifications. In addition to minor assembly variations, neither of the two complete separators nor any of the three replacement media bundles met the Savannah River required pressure drop limits (0.95 ± 3.05 in. WC) at 1600 cfm. They ranged from 1.19 to 1.30 in. WC, approximately 20-30% above specification.

Separator description and test performance are presented in the following subsections.

C.1 DESCRIPTION

Appearance: see Figures 31 and 32 for photographs.

Type:
321 SR, Otto H. York Company designation.
DP812 - Appendix B, Savannah River specification[7].
Knitted fine fiber media packing, supported by grids on both sides, enclosed in a frame with flanges for gasket sealing in horizontal flow and lower entrainment drain provision.

Size:
24 in. H x 24 in. W x 2 5/8 in. D, overall case
3/4 in. w flanges, all around both faces.
3.5 sq ft face area, inlet and outlet.
3/8 ø - 2 drain holes in lower side at outlet flange; 1/4 in. nipples were cut off to fit MSA duct.

Materials:
Teflon fibers, 0.0008 in. in diameter, 1200 D - 180 F - OT.
Type 304 ss wire, 0.006 in. diameter, knitted with above.
Type 304 grids (1/4 in.), case (16 Ga), tie wire (16 Ga)

Assembly:
All welded case, grids and support rods.
12 layers knitted media, oversized for compression fit into case and laced with support wires and rods.

Weight: 20 lbs

Rating: 1600 cfm and in accord with DP812[7], adequate for HEPA protection, ~99% efficiency on 1-5 micron size in air-steam-water test. See Figure Cl for calculated efficiencies of *typical* fiber beds.

C.2 ETF INSTALLATION

The York Separator was installed in the ETF with general arrangement as indicated in Figure 1. The upstream face was sealed using a gasket. The drain holes at the outlet flange were directly over the separated water sump. The 5 in. long duct area immediately downstream of the separator was fitted for the first collection and measurement of penetration reentrainment. The next 7 in. long Plexiglass section served as the second penetration collection area. The final 12 in. duct length, up to the inlet face of the HEPA, was the third area for penetration collection. The total distance-from the separator outlet face to the HERA inlet face was thus 24 inches,

C.3 TEST RESULTS

The York Type 321 SR Separator as described and installed was operated at ambient conditions in accord with the general test plan of Section 4. Summarized data are presented in Tables Cl and C2 and in figures C2, C3 and C4, with-additional observations as follows:

C.3.1 ETF Test Observations

Circulating air flow at ambient pressure and temperature was started at 1000 cfm to obtain a data profile at rated HEPA flow. It was then increased to 1600 cfm for the rated separator flow profile and held at rated separator flow for the balance of testing under entrainment'conditions. Cooling water flow to the heat exchanger was adjusted as required to keep the circulating gas stream temperature from escalating.

Entrainment was initiated at a low rate (47 lbs/hr) of large (100 micron MVD) particle size using one bank of eight TX-1 nozzles operating at 40 psi. About eleven minutes following introduction of this entrainment loading, water started coming through the downstream side of the separator, The Teflon separator media was bared out (1/2 to 1 in.) between the outlet grid openings (a tendency for this delicate media). Water first dropped off the media where it was protruding and fell into the first penetration collection sump below. Water droplets also began blowing straight out from the media at about 1/2 inch above the lower flange at the separator outlet face. Some of these drops were carried into the

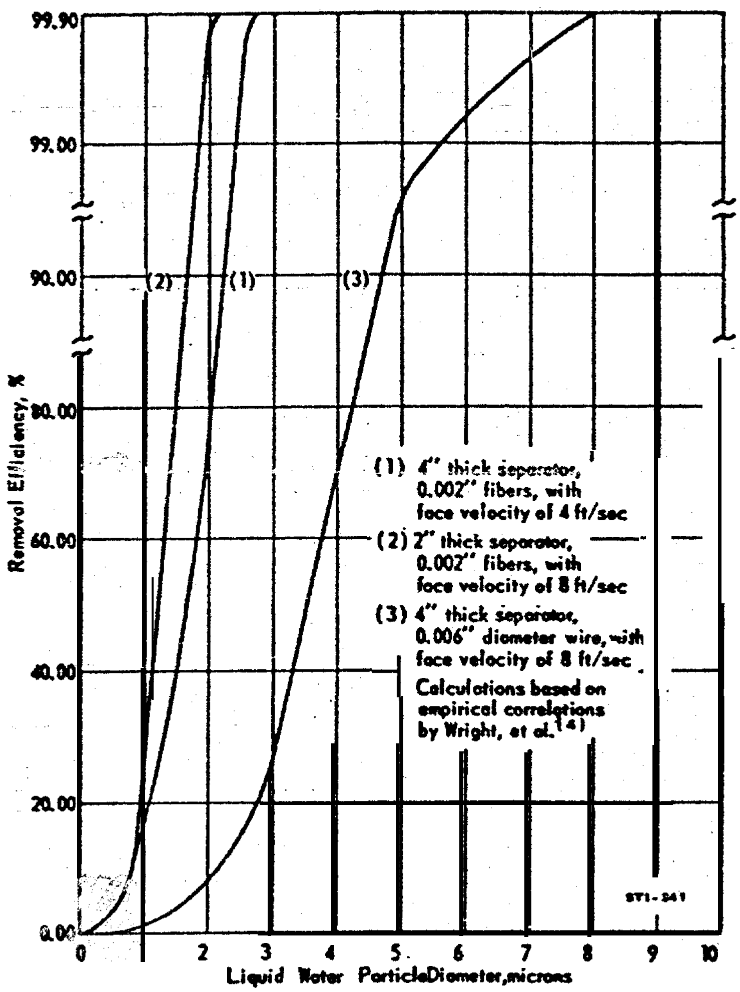


FIG. Cl - CALCULATED REMOVAL EFFICIENCIES OF SEPARATORS

Reproduced from DP-812[7]
Fig. 24, 3age 63

TABLE Cl - YORK SEPARATOR 'PERFORMANCE DATA'

ETF Test-20
November 5, 1970
Atmospheric Pressure
RH: 100%

Time	Temperature °F HEPA Out	HEPA In	Separator Out	Separator In	Heat Exchanger Out	Heat Exchanger In	Pressures Spray Water	Spray Water psig	Pressure Drop inches WG HEPA	Pressure Drop inches WG Separator	Spray size µ MVD	Flow Rates Gas Stream CFM	Separator Removal lbs/hr	Separator Penetration
									0.90	0.57		1000		
0910									1.57	1.29		1600	Dry Readings	
0939	93	91.5	91.5	93	96	9[illegible]		40	1.59	1.29	100	1600		
1003	94	92	92	93	99.5	99.5	96.5	40	1.62	1.64	100	1600	33.4	13.3+0+0
1048	97	95	95	96.5	102	104.5	101.5	40	1.68	2.03	100	1600	17.6	91.5
1130	97.5	95	95	97	101	105	97	40	1.70	2.09	100	1600		+2.4+0.3
1230	95.5	93.5	93.5	95	95.5	95.5	97	40	1.73	2.18	100+10	1600		
1330	97.5	95.5	95.5	97.5	97	97.5	97	40	1.76	2.22	100+10	1600		
1410	97	95	95	97	97	97	97	40	1.77	2.22	100+10	1600	18	96.8
1500	97	95	95	97	96.5	97	97	40	1.776	2.22	100+10	1600		+3.4+
1530	96	94.5	94.5	96	96	96.5			1.78	1.83	10	1600		
1600	95.5	93	93	95	95	95			1.783	1.60	10	1600	0.81	1.44+
1655	94.5	92.5	92.5	94	94.5	94.5			1.79	1.60	10	1600		
1705														No visible fog at any time

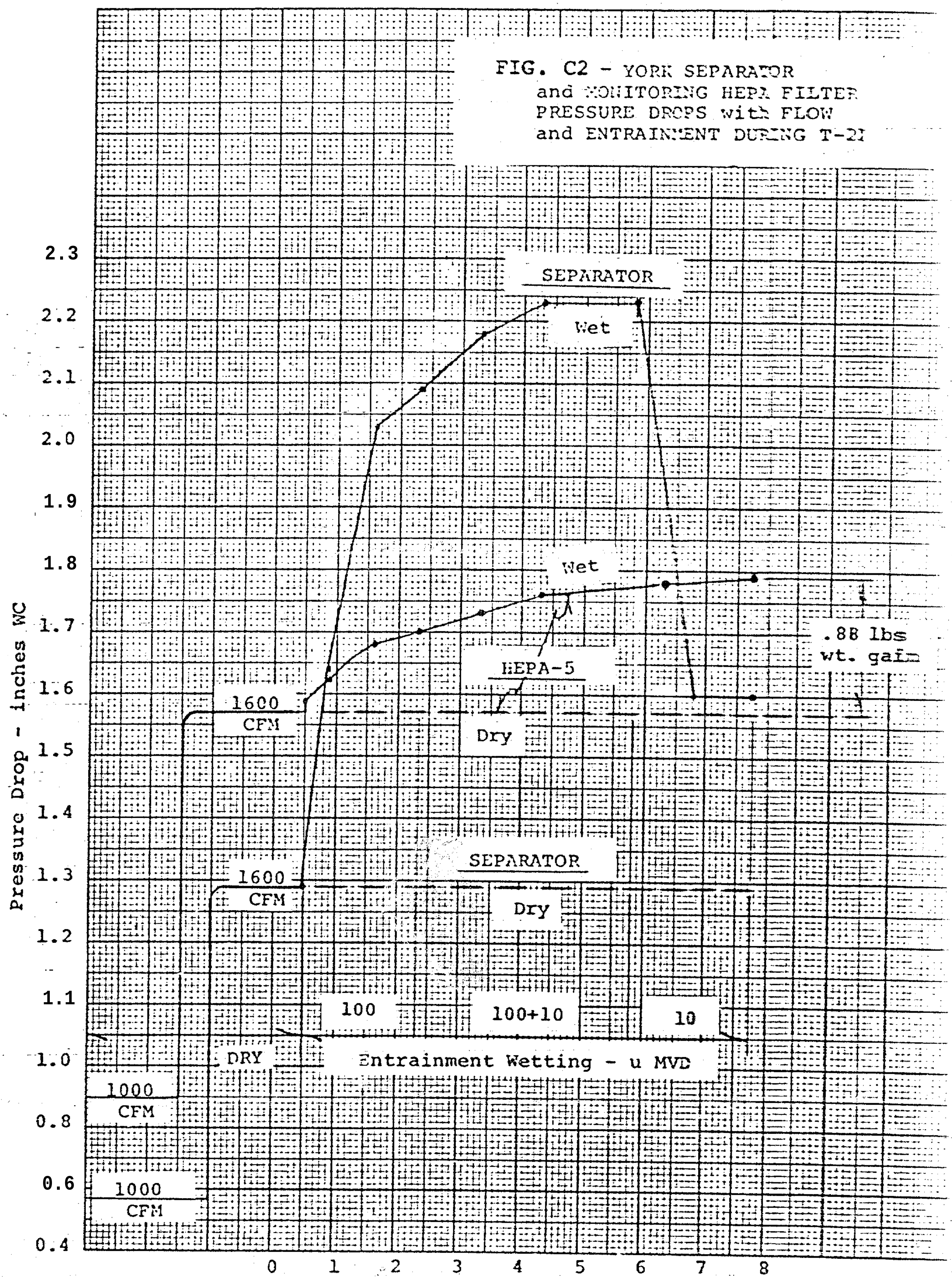
7.3 hrs, Entrainment Time

ITEM	Before Test 0.3 µ DOP Pene %	ΔP in.WC	Flow CFM	0.6 µ DOP Pene %	ΔP in.WC	Flow CFM	After Test 0.3 µ DOP Pene %	ΔP in.WC	Flow CPM	0.6 µ DOP Pene e	ΔP in.WC	Flow CFM
SEPARATOR	93	0.57	1000	72 69 60	 1.24 1.85	 1600 2000	93	0.57	1000	90 79 74		1000 1000 1000
HEPA-5	0.001	0.90	1000				1001	0.89	1000			

TABLE C2 - YORK SEPARATOR
AVERAGE CONDITIONS FOR ETF TEST 20

Item	Description	Value
1	HEPA Outlet Temperature, F	95.86
2	HEPA Inlet Temperature, F	93.86
3	Separator Outlet Temperature,- F	93.86
4	Separator Inlet Temperature; F	95.54
5	Spray Water Temperature; F	97.69
6	Heat Exchanger Cutlet Temperature, F	97.27
7	Heat Exchanger Inlet Temperature, F	97.72
8	System Pressure, psig	Atmospheric
9	HEPA Pressure Drop, in&es WC	1.71
10	Separator Pressure Drop, inches WC	1.35
11	System Flowrate, CFM	1600
12	Separated Entrainment:	
	100 µ MVD, lbs/hr	to 33.4
	100 + 10 µ MVD, lbs/hr	18
	10 µ MVD, lbs/hr	0.11
13	Penetrated Entrainment (Dropout):	
	100 µ MVD, lbs/hr	to 94.2
	100 + 10 µ MVD, lbs/hr	to 100.2
	10 µ MVD, lbs/hr	1.44

FIG. C2 - YORK SEPARATOR and MONITORING HEPA FILTER PRESSURE DROPS with FLOW and ENTRAINMENT DURING T-2I



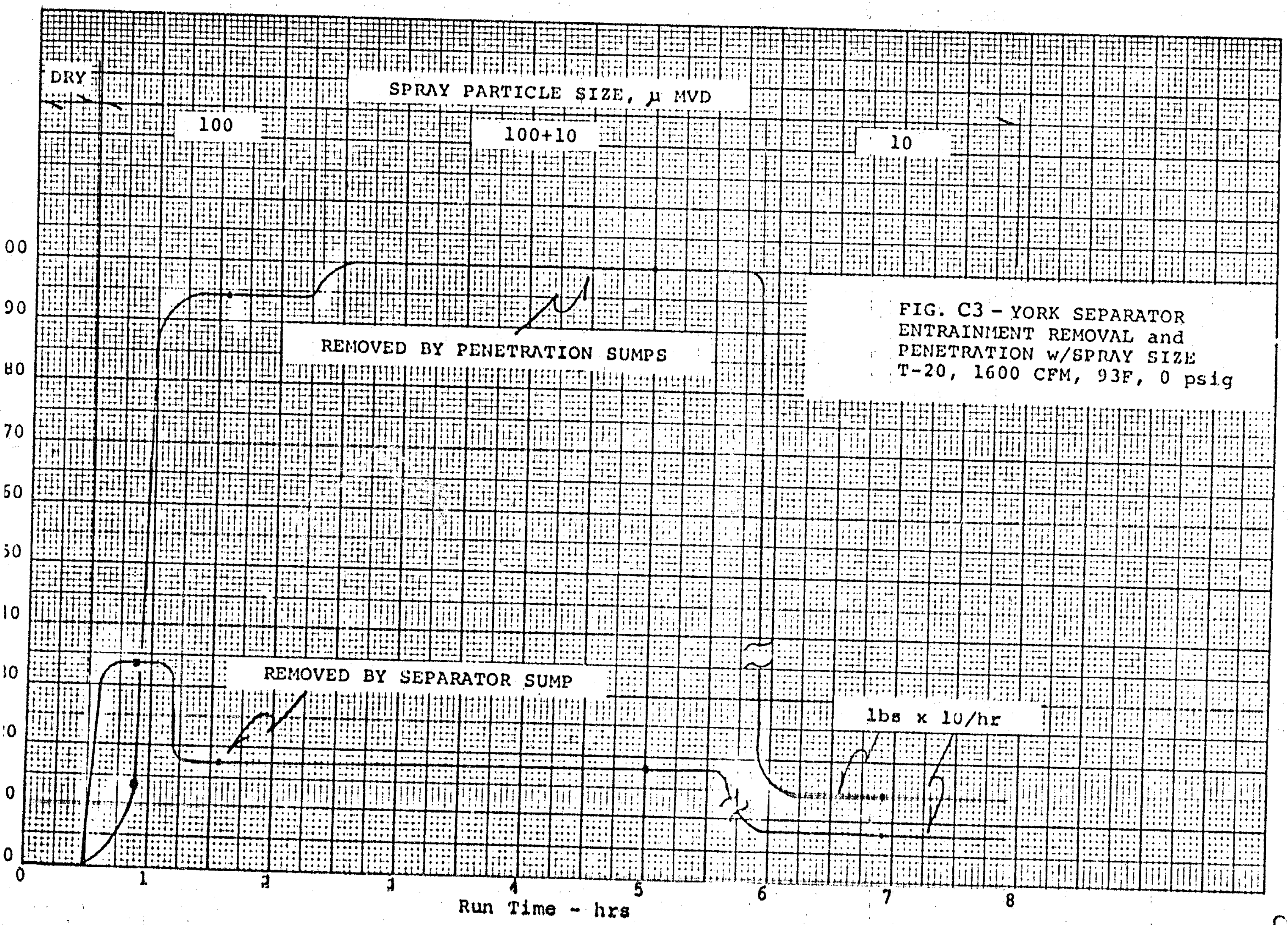


FIG. C3 - YORK SEPARATOR ENTRAINMENT REMOVAL and PENETRATION w/SPRAY SIZE T-20, 1600 CFM, 93F, 0 psig

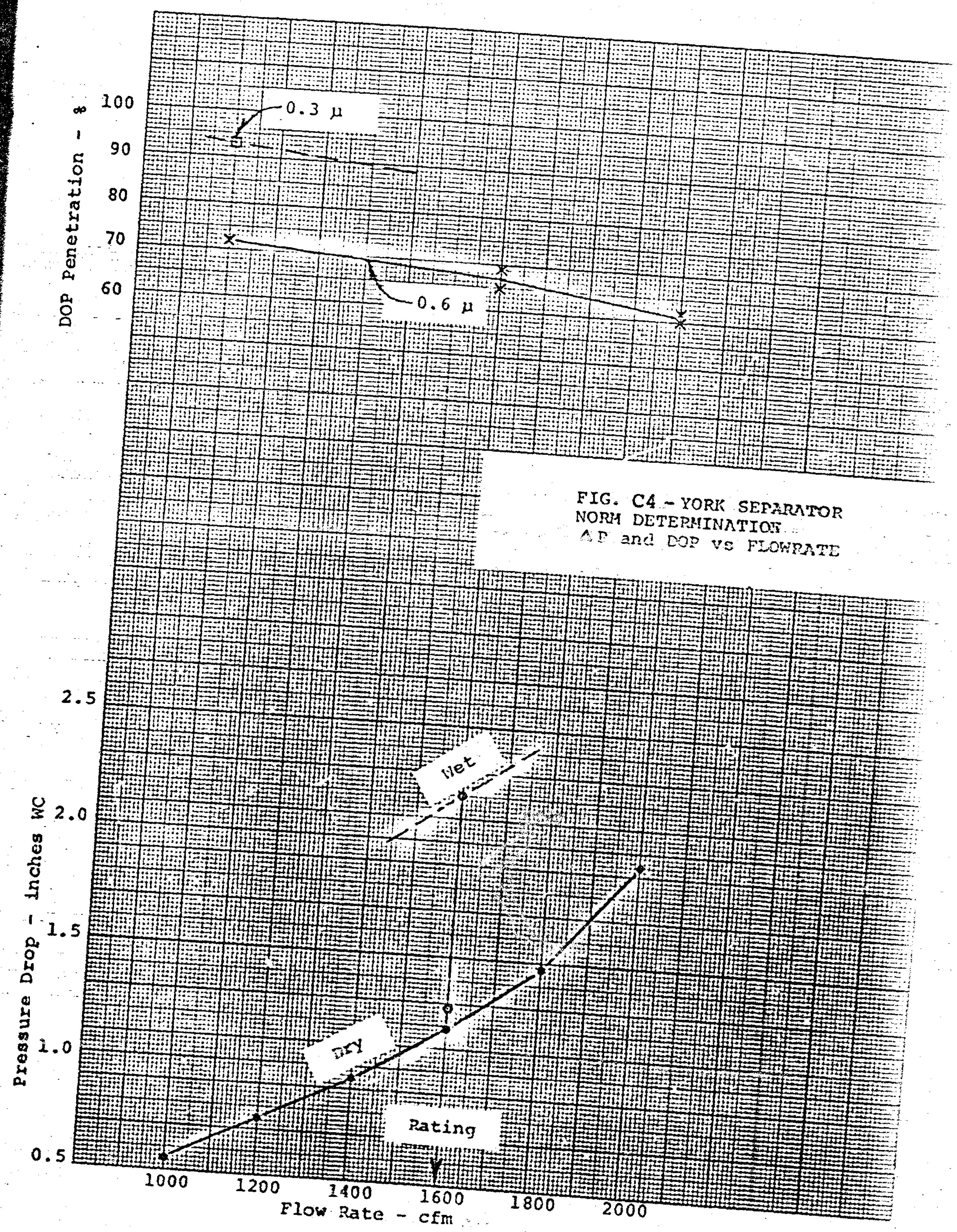


FIG. C4 - YORK SEPARATOR
NORM DETERMINATION
ΔP and DOP vs FLOWRATE

8-10 in. up the walls at this point. At this time, the entrain-ment removal rate from the separator case was 33.4 lbs/hr, accompanied by a 13.3 lbs/hr penetration rate from the first sum with no measurable rates yet from the second and third sumps.

Large (100 micron MVD) entrainment rate was then increased to ~112 lbs/hr by turning on a second bank of TX-1 nozzles at 40 psi, Separator'penetration rate increased and re--entrained droplets were coming off the back of the-separator med from the lower 16 in. portion of the outlet face. Only the top 7 in. section was free of reentrainment. Reentrained droplets w carried up to 18 inches downstream of the separator, only.6 inch: from the face of the HEPA. During this period, entrainment remo rate from the separator case drain sump was 17.6 lbs/hr; penetra-tion rate from the first collection sump was 91.5 lbs/hr; from th second, 2.4 lbs/hr; and from the third, 0.3 lbs/hr. There seemed to be no point in increasing entrainment loading to a higher lev

The fine (l-10 micron) particle rate'was then increased by adding the output of all thirty-two 1A nozzles together with the sixteen TX-1 nozzles on-stream. Total mixed entrainment loa reached ~120 lbs/hr, 1.25 lbs/1000 cu ft -- well below the York rating. Removal distribution was 18 lbs/hr from the separator case;--96.8 lbs/hr from the first penetration sump, 3.4 lbs/hr fro the second penetration sump, and an unmeasured smaller rate from the third penetration sump. No fine fog penetration was visible.

To further check fine. (l-10 micron) entrainment perform-ance, all TX-1 nozzles were turned off, leaving only the (10 micr MVD) 1A nozzles operating. Entrainment loading-was reduced to. 2.25 lbs/hr with no fine fog penetration visible but with similar reentrainment of large particles occurring on a reduced scale. Removal distribution was 0.81 lbs/hr from the separator case and 1.44 lbs/hr from the first penetration sump; negligible amounts reached the other two separator sumps. Impactor samples taken during 10 micron MVD entrainment operation did not detect any 2.5 10 micron particle size penetration. A series of pictures were taken to indicate separator installation and -operation.

C.3.2 Summary of HEPA Monitoring

HEPA pressure drop increased at a gradual rate during the-test, irrespective of entrainment loading or particle size, a shown in Figure C2. The dry pressure drop of 1.57 in. WC at 1600 cfm increased 14% to 1.79 in: WC at the end of the run, Wat pick-up by the HEPA was measured as 14 oz by weight difference. This was evaporated during final differential pressure-DOP measur ments following the run. There was no noticeable change in HEPA differential pressure increase when fine (10 micron MVD) entrainm loading was studied. Direct impingement on the HEPA of larger re-entrainment leaving the separator was avoided by holding loading and velocity at levels below those which would reach the HEPA, located 24 inches downstream. Separator penetration under th

C.3.3 Summary of Separator Performance

Separator differential pressure of 1.29 in. WC was 29% above Savannah River specifications[4], to which this separator was ordered. This differential pressure increased 72% to 2.22 in. WC under maximum tested entrainment loading of 1.25 lbs/1000 cu ft. --Separator differential pressure varies somewhat with loading, ranging from a 24% increase with wetting at 0.024 lbs/1000 cu ft to a 72% increase at 1.25 lbs/1000 cu ft maximum loading tested.

Separator efficiency,.based on draining all removed entrainment through the separator case-drain holes provided, was very low. Removal efficiency ranged-from a high of 36% at the lowest loading with fine (10 micron MVD) particles to 15.7% at maximum loading tested. Penetration rate is shown in Figure C3 and itemized in- Table Cl.

Separator-efficiency-based on agglomerization of fine particles was ~100% since no visible mist or fog was observed in the separator effluent and none-was measured by impactor sampling

C. 4 CONCLUSIONS

The York Separator assembly, as supplied and test&, did not prevent water entering the downstream air space. Entrainment removal efficiency with any size particles was measured at <40%.

D. AAF TYPE T SEPARATOR

An AAF Type T Separator, as furnished for the Connecticut Yankee.8 Reactor Containment System, was purchased in a special 24 in. x 24 in. size to fit the ETF for performance evaluation in this program,

The-separator was received with a 2 1/2 in. threaded drain-nozzle protruding beyond the 24 in. maximum allowable width; this was cut off for MSA installation in the ETF. During ambient tests, the only performance objection was leakage of removed entrainment from the two corner welds on the lower outlet portion -of-the separator. It-was -assumed that this leak resulted from an oversight on the part of normal quality control not exercised for this special size module. These defective weld areas were therefore sealed with RTV-108, in order to continue test operation at incident conditions. Separator description and test performance are presented in the following subsections.

D.1 DESCRIPTION

Appearance:	See Figures 33 and 34 for photographs,
Type:	"T", AAF Extractor Designation 491-118, Serial or AAF Control number. Figure 1 and 2 - MSA PO D17072 ordering information. AAF Sketch ---Prod. Engr., 6-17-70, A. O'Nar confirming vane and hook inlet, non-woven fiber pad outlet.
Size:	24 in. W x 24 in. H x 24 in. D, overall, excluding drain nozzle. 22 1/4 in.-W x 22 1/8 in. H x 24 in. D, overall case without mating flanges. 22 in. W x 17 7/8 in. H, face opening, inlet and outlet. 2 1/4 in. ID side drain hole, nozzle ground off flush. 1.965 sq ft minimum face area.
Materials:	Stainless steel: case (16 Ga), baffles (26 Ga), mating flanges (11 Ga), grids (3/16 dia) Fiberglass - bonded media pads; type not specified but probably AAF Ty M-105 in accord with NYC-32506[8].
Assembly:	All welded, except for mechanical arrangement of media grids for replacement of

Weight: 111 lbs

Rating: 1140 cfm and in accord with NYO-3250-6[8] report, which tested briefly for HEPA protection to: 261 F - 40 psig, 1000 cfm size separator, 1 gpm entrainment loading, of particle size as generated by G-10 nozzles operated at 20 psi differential pressure giving ~800 micron MND, 2400 micron MVD.

D.2 ETF INSTALLATION

The AAF Separator was installed in the ETF with general arrangement as shown in Figure 1. Because of its increased depth, mounting flanges for positioning the separator drain nozzle over the ETF sump were requested. These flanges were gasket-sealed so that the removed entrainment draining from the separator case drain hole would be withdrawn for measurement through the separator case drain sump (14). The separator inlet section extended 11 in. into the large (TX-1) spray chamber necessitating removal of several banks of TX-1 nozzles and obscuring the view from the sight glass (SG-2). For ambient test, with the 7 in. long Plexiglass sight section installed, the separator outlet section extended 5 in. into this section. This left 14 in. of duck to the inlet face of the downstream HEPA; 2 in. of Plexiglass piped for penetration measurement, plus 12 in. of the final penetration collection sump. For incident testing at elevated temperature and pressure, the Plexiglass sight section was omitted from the ETF. This positioned the separator outlet over the final penetntion collection sump, leaving a distance of 7 in. to the HEPA inlet.

D.3 TEST RESULTS AT AMBIENT CONDITIONS

The AAF Type "T" Separator, as described and installed, was operated at ambient conditions in accord with the general test plan of Section 4. Summarized data are presented in Tables D1 and D2 and in Figures D1, D2 and D3, with additional observations as follows,

D.3.1 ETF Ambient Test Observations

Air circulation was started at 1000 cfm to get a differential pressure profile at HEPA rating. It was then increased to the separator rating of 1140 cfm for this differential pressure profile, and held at rated separator flow for the balance of testing under entrainment conditions. Cooling water to the heat exchanger was adjusted as required to keep the circulating air stream temperature from escalating. A series of photographs was taken to illustrate separator installation and operation. Impactor samples

TABLE D1 - AAF SEPARATOR PERFORMANCE DATA

ETF Test - 21
November 12-13, 1970
Atmospheric Pressure
RH: 85% start, 100% @ end

Time	Temperature °F							Pressures			Spray	Flow Rates		
	HEPA		Separator		Heat Exchanger		Spray Water	Spray Water psig	Pressure Drop Inches WG		Size μ MVD	~~Gas~~ Stream CFM	Separator Removal lbs/hr	Separator Penetration
	Out	In	Out	In	Out	In			HEPA	Separator				
									0.9	0.7		1000		
0915									1.08	0.8		1140	Dry Readings	
0945	81.5	79	79	83	84.5	82.5	88	40	1.08	0.85	100	1140		
1030	93	91	91	90	94.5	95.5	94	40	1.09	0.93	100	1140	59	
1053	96	93.5	93.5	95.5	98	98	94	40	1.10	0.96	100	1140	115	
1124	94.5	93	93	93	94.5	98.5	94	40	1.115	0.96	100	1140	311	
1150	85.5	85.5	85.5	83.5	86	86	78	40	1.11	0.97	100	1140	428	4.5 from defective
1240	83.5	82.5	82.5	81.5	84.5	83.5	74	80	1.125	1.03	70+10	1140	443	weld only
1340	82.5	82	82	81.5	82.5	82.5	74	80	1.14	1.10	70+10	1140	444	
1400	82.5	82	82	82.5	84	83	74	80	1.155	1.11	70+10	1140		
1500	86	84.5	84.5	86	87.5	86			1.198	1.14	10	1140		
1530	87.5	86.5	86.5	87	88.5	91			1.22	1.16	10	1140	6.4	
1557	87.5	87	87	87	88.5	88			1.23	1.16	10	1140	5	
1635	88.5	88	88	88	88.5	88.5			1.23	1.16	10	1140	4.5	
1647	7 hours Entrainment Time - 1st day Nov. 12, 1970													No other visible or measured penetration
0815									1.21	1.12		1140		
0830	81.5	81	81	78.5	82.5	81.5	73.5	80	1.21	1.12	70	1140		
0850	85	82.5	82.5	84.5	86	84.5	73	80	1.21	1.16	70	1140		
1035	95	94.5	94.5	94.5	95	94.5			1.28	1.20	10	1140	4.75	
1130	91	90.5	90.5	90.5	92	91.5				1.195	10	1140		
1300	91.5	90.5	90.5	91	92.5	91.5			1.28	1.185	10	1140		
1357	91.5	90.5	90.5	91	92	91.5			1.28	1.18	10	1140	3	
1514	91.5	90.5	90.5	90	92.5	91			1.31	1.16	10	1140	2.25	
1620 1623	80hourstrainment Tim90.59½.2nd day, Nov. 13, 1970								1.31	1.16	10	1140		

15 hrs Total Entrainment Time

ITEM	Before Test						After Test					
	0.3 μ DOP			0.6 μ DOP			0.3 μ DOP			0.6 μ DOP		
	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM
SEPARATOR	95	0.60	1000	98	0.36	712	98		1000	96	0.36	712
				93	0.78	1140				95	0.85	1140
				90	1.28	1425				90	1.26	1425
HEPA-12	0.005	0.90	1000				0.006	0.88	1000			

TABLE D2 - AAF SEPARATOR
AVERAGE CONDITIONS FOR-ETF TEST-21

Item	Description	Value
1	HEPA Outlet Temperature, F	88.3
2	HEPA Inlet Temperature, F	87.3
3	Separator Outlet Temperature, F	87.3
4	Separator Inlet Temperature, F	87.6
5	Spray Water Temperature; F	81.7
6	Heat Exchanger Outlet Temperature, F	89.3
7	Heat Exchanger Inlet Temperature, F	89
8	System Pressure, psig	Atmospheric
9	HEPA Pressure Drop, inches WC	1.09 min - 1.20 - 1.23
10	Separator Pressure Drop, inches WC	0.93 min - 1.09 - 1.16
11	System Flowrate, CFM	1140
12.	Separated Entrainment:	
	100 μ MVD, lbs/hr	59 to 428
	70 + 10 μ MVD, lbs/hr	444
	10 μ MVD, lbs/hr	6.4 -to 2.3
13	Penetrated Entrainment (Dropout): Excluding Case Leakage)	
	100 μ MVD, lbs/hr	0
	70 + 10 μ MVD, lbs/hr	0
	10 μ MVD, lbs/hr	0

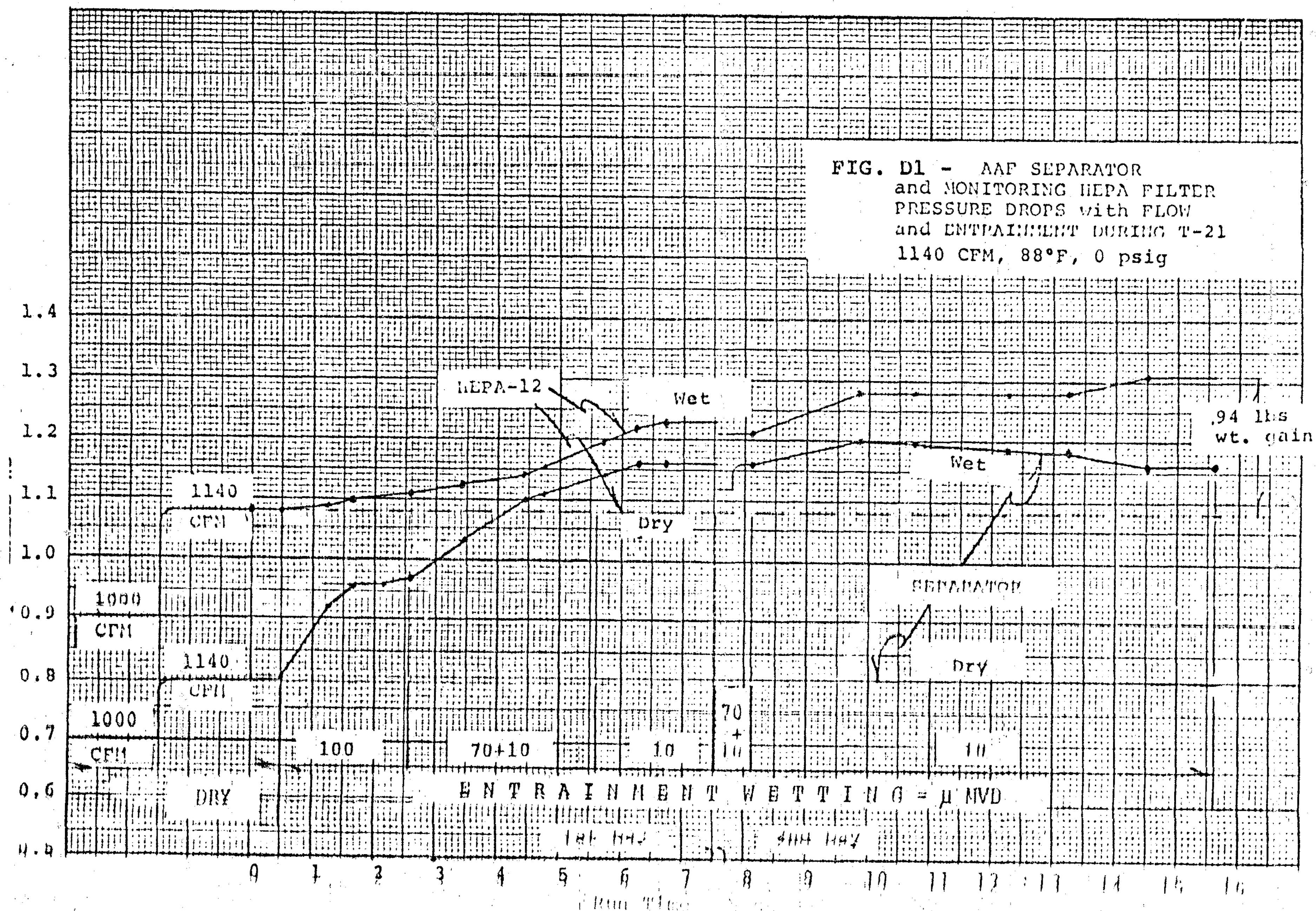


FIG. D1 - AAF SEPARATOR and MONITORING HEPA FILTER PRESSURE DROPS with FLOW and ENTRAINMENT DURING T-21
1140 CFM, 88°F, 0 psig

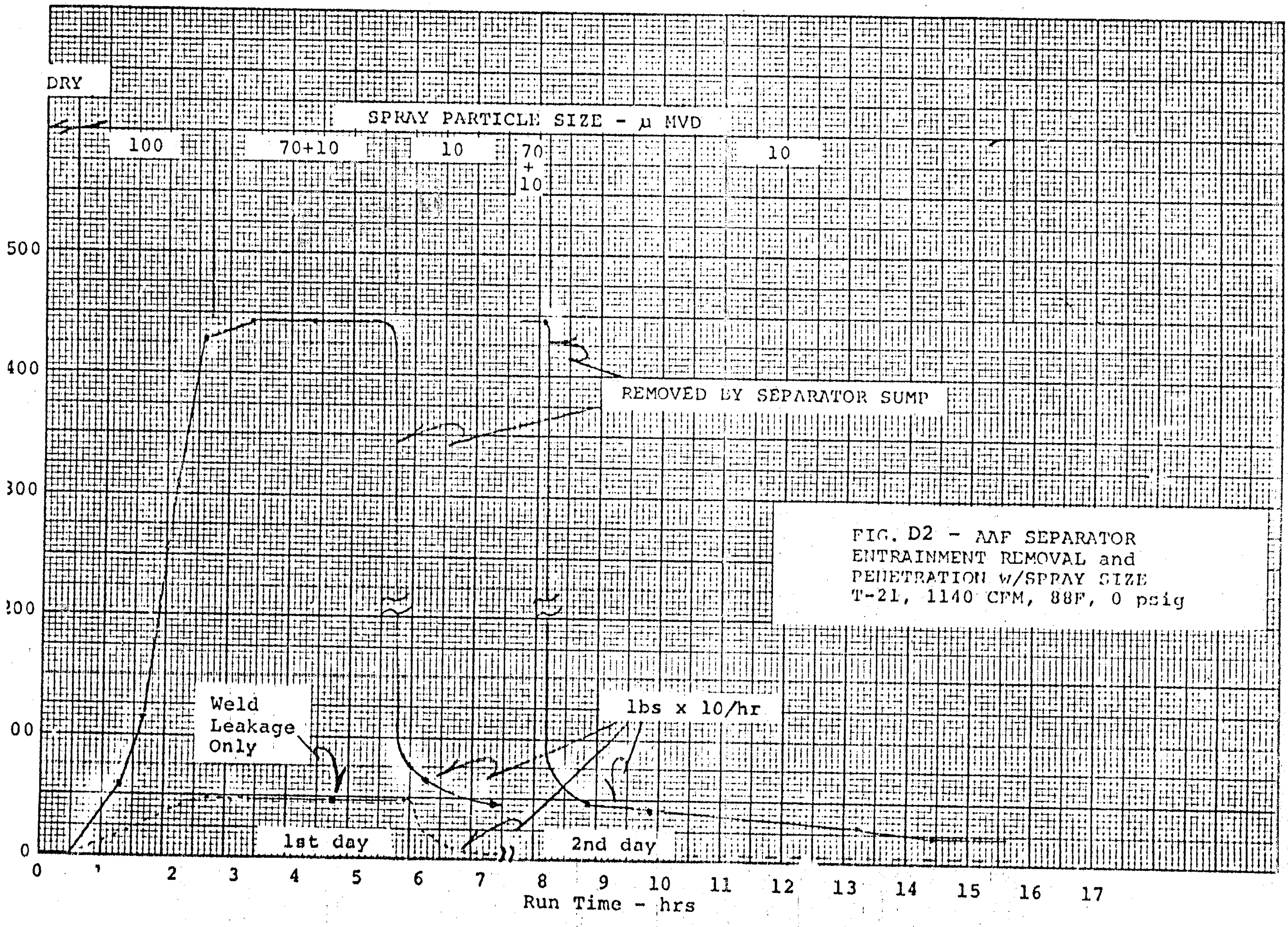


FIG. D2 - AAF SEPARATOR ENTRAINMENT REMOVAL and PENETRATION w/SPRAY SIZE
T-21, 1140 CFM, 88F, 0 psig

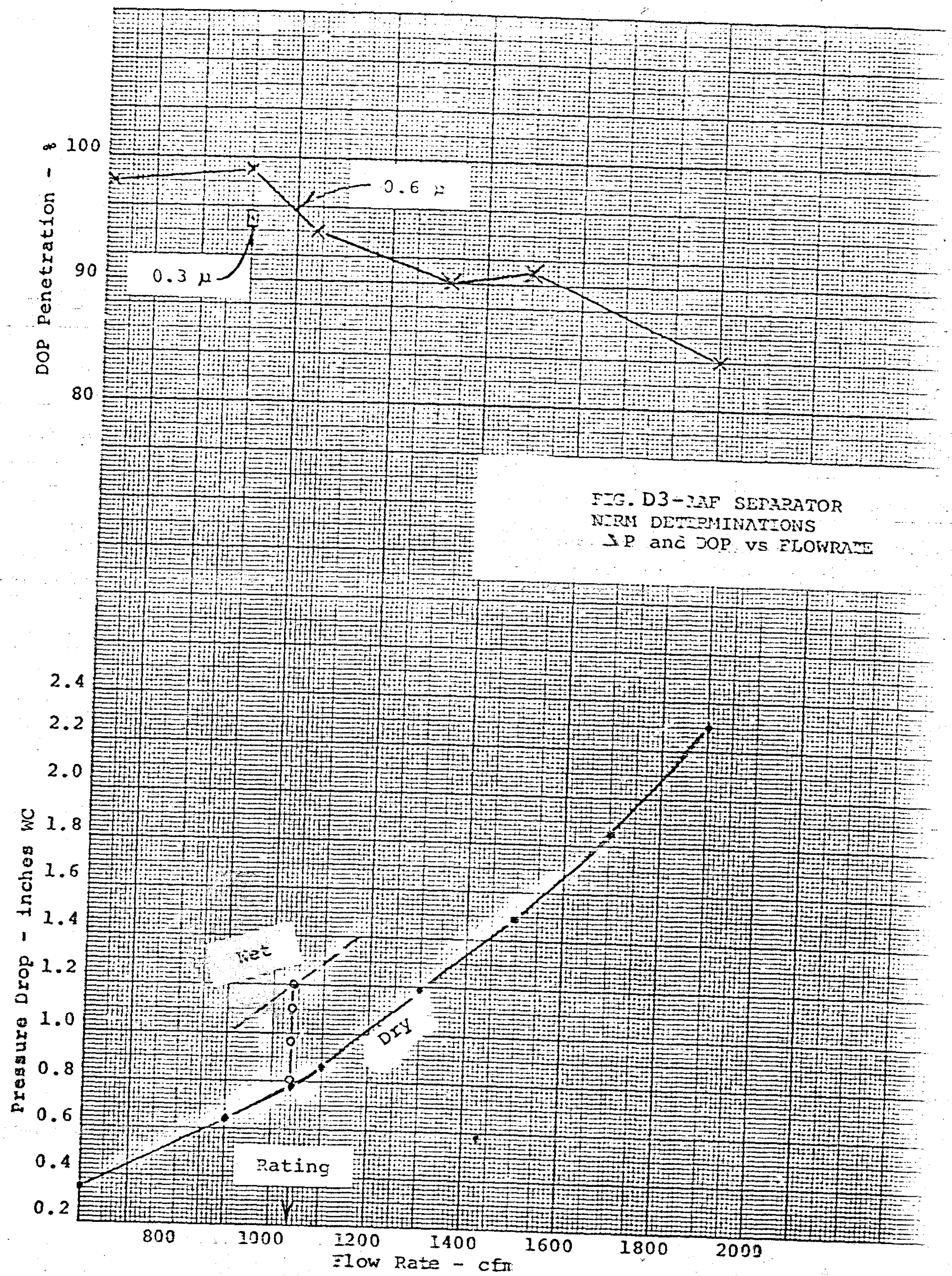


FIG. D3-RAF SEPARATOR
NORM DETERMINATIONS
ΔP and DOP vs FLOWRATE

Entrainment was initiated at a low rate (59 lbs/hr) of large (100 micron MVD) particle size, using one bank of TX-l nozzles operating at 40 psi. No penetration of fog or reentrainment was visible. Large particle entrainment loading was then increased in steps until all ($6) TX-1 nozzles were in operation at 428 lbs/hr entrainment removal with no visible penetration,

The fine (l-10 micron) particle rate was then increased by raising. TX-1 nozzle pressure to 80 psi (~70 micron MVD) and adding the 10 micron MVD output of all (39) 1-A nozzles for a combined maximum loading of 444 lbs/hr entrainment removal rate. At this point, drops were observed forming at both lower outlet corners of the separator, apparently from-defective welding of these areas. This leakage dropped into- the Plexiglass section directly below the separatoroutlet and was -measured. at a rate of 4.5 lbs/hr, approximately 1% of loading. This fabrication defect was not considered to be a penetration characteristic of this separator and was sealed, using RTV-108, for incident test operation.

To further check fine (1-10 micron) entrainment performance, all TX-l nozzles were turned off, leaving only the 10 micron MVD (1-A) nozzles in operation. Test operation at this fine particle size loading was continued for a second day to verify lack of penetration in this range during extended operation and to permit adequate impactor sampling. No fine (1-10 micron) particle penetration was detected. Some degeneration of the fiber mat was becoming evident. Within the first-hour of operation, some individual fibers were observed extending straight but, as much as 6-8 inches, from the downstream face of the separator, The number of fibers so extending from the separator seemed to increase with operating time over this test run.

D. 3.2 HEPA Monitoring Summary of Ambient Test

HEPA-12 pressure drop increased at a gradual rate during this test, irrespective of entrainment loading or particle size as shown by Figure D1. The dry pressure drop of 1.08 in, WC increased 21.3% to 1.31 in. at the end of the run. Water pick-up by the HEPA at the end of the run was measured as 0.94 lbs by weight difference. This was evaporated during final differential pressure-DOP measurements made following the run. No significant change was observed in the slope of pressure drop increase with respect to entrainment loading or particle size..

D.3.3 Separator Performance Summary of Ambient Test

Pressure drop of the AAF Type T Separator, at 1140 cfm rated flow with air only, was 0.8 in. WC. This increased somewhat with respect to -entrainment loading -- 21% to 0.97 in. at 434 lbs/hr. A further increase occurred with operating time and 10 micron MVD added loading. A high of 1.2 in. WC (50% increase) occurred after reaching the peak entrainment test loading of 450 lbs/hr, 6.6 lbs/1000 cu ft. Removal capacity, rated or flooding, was not attained. The differential pressure decreed. to 1.16 in. WC (45% above dry value) at low (<3 lbs/hr) loading of 10 micron MVD size entrainment. No separator entrainment penetration was detected at these test conditions.

D.4 CONCLUSIONS - AMBIENT TEST

The AAF Type T Separator's removal efficiency was essentially 100% down to 2 micron particle size, based on no detectable penetration, Permissible entrainment loading capacity is 6.6 lbs/1000 cu ft of mixed particle size, ≥ 70 micron + 10 micron MVD, including at least 1% of the 10 micron MVD size particles alone or in combination with the bulk loading of larger sized particles.

Leakage through defective welds in the lower removal-collection portion of the separator was not included as a normal separator penetration characteristic. Stringing of fibers 6-8 in. cut from the packed bed at the separator outlet seemed to be an indication of bed deterioration since the packing was not completely retained within the separator housing. However, since this apparently did not influence entrainment removal efficiency, and since there was no change in final 0.5 DOP efficiency of the separator, this factor was discounted.

The AAF Type T Separator was considered suitable for additional performance testing at incident conditions.

D.5 TEST RESULT-S FOR INCIDENT TEST

The AAF Type T Separator, as described for testing at ambient conditions (T-21), was subsequently test-operated (T-24) at incident conditions of 271 F - 47 psig in Run T-24. Summarized data arc presented in Tables D3 and D4 and in Figures D4 and D5, with additional observations as follows.

D.5.1 ETF Incident Test Observations

Following ETF installation (Section C.2), the AAF Type T Separator was operated at ambient conditions to get dry differential rpessure profiles at 1100 and 1140 cfm, rated HEPA and separator flows. With 5 psi ETF initial air pressure, 18 TX-1 nozzles generating ≥100 lbs/hr of approximately 100 micron entrainment loading, full steam was supplied to bring the ETF up to incident conditions. Desired conditions of 271 F - 47 psig were reached within 1.3 hours; an additional three hours were required to get spray temperature to 271 F because of limited heater capacity. Entrainment particle size of approximately 100 micron MVD varied

TABLE D3 - AAF SEPARATOR INCIDENT TEST DATA SUMMARY

ETF Test-24
January 13-14, 1971
Incident: 271F-47 psig @ 29" Barometric
RH, %: 93 Min, 96 Avg, 98.2 Max

Time	Temperatures, °F HEPA Out	HEPA In	Separator Out	Separator In	Heat Exchanger Out	Heat Exchanger In	Spray Water	Pressures Spray Water psig	System psig	Pressure Drop inches WG HEPA	Pressure Drop inches WG Separator	Spray Size µ MVD	Flow Rates Gas Stream CFM	Separator Removal lbs/hr	Separator Penetration
										0.88	0.68		1000		
0940			Ambient					0	Atmos	1.08	0.88		1140	Dry	
1000	197	195	195	201.5	208.5	203.5		80		1.20	1.33	100	1140	Approaching Incident	
1100	270.9	271	273.0	274.8	276.2	274.9	170	80	46.8	1.364	1.875	100	1140	40-125	18 TX-1
1200	270	271	272.4	272.4	275.5	274.5	175	80					1140	40-125	
1300	270	270.5	271.8	271.6	275.4	274.7	222	80	47.40	1.35 1.31	11.89	100 100	1140	44-164	
1400	290.S	271.5	272.8	272.3	275.6	274.7	271	80	46.9	1.308	1.89	100	1140	50-160	No Visible
1500	269.5	270.5	271.8	271.5	275.8	273.7	272	80	47.2	1.294	1.89	100	1140	45-175	
1600	270	271	272.6	272.6	278.3	274.4	270		[illegible]	[illegible]	1.88	100	1140	75-174	or
1700	270	271	271.9	272.3	278	274.2	272	80	47.2	1.304	1.87	100	1140	95	
1800	210	271	271.6	271.5	274.3	273.4	273	80	47.2	1.32	1.86	100	1140	100.0	Measureable
1900	269.5	270 5	271.6	270.9	273.9	273.1	273	80	47.0	1.304	1.82	100	1140	57	9 TX-1
2000	270	271'	272.4	272.1	275	274.4	273	80	47.6	1.30	1.82	100	1140	57	Penetration
2100	270	272.4	271.4	271.4	273.9	274.6	273	80	47.5	1.292	1.83	100	1140	57	
2200	270	271	271.9	271.1	274.5	273.5	272.5	80	47.4	1.392	1.81	100	1140	55	at
2300	a70	272	270.5	269.8	273	272.4	273	80	47.6	1.31	1.80	100	1140	40-100	
2400	270	271	270.4	269.5	272.6	27i.8	273	80					1140	55.	any
0100	270	271	?70.1	27'0.3	272.9	272.4	272.!	80	47.5 47.5	1.356	1.81 1.78	,100 100	1140	40-100	
0200	270.5	271.5	272.3	27'0.3	273.4	272.6	272.5			1.356		100	1140	4-85	Time
0300	270.5	271.5	270.7	269.4	272.6	272.2	73	80	47.7	1.36	1.80	100	1140		
0400	270.5	271.5	270.2	269.2	272.5	271.6	372.5	80	47.5	1.36	1.1.80	L00	1140		. I
0500	270.5	271.5	271	270.5	271.4	2220.5	72.5	Steam	47 7	1 36	1 776	10	140	<	I-A
0600	271	272	271.8	271.7	271.8	271.6	272.5		[illegible]	[illegible]	[illegible]		1140		
0700	270	271	270.3	269.1	270.8	271.3	273	3:	47.7	1.374	1.82	10, 10'	1140		Visible
0800	270	271	270.7	270.4	271.2	270	273	98	47.2	1.38	1.80	10	1140		Fog
0900	270	271	270	271.3	269.7	267.9	273	63	47.2	1.38	1.89	10	1 1 4 0		Entering
1000	270	271	270.9	270.4	270.9	269.8	273	63	47.2	1.40 1.392	1.80	10	1140		Separator
1100	270	271	270.7	270.5	272.5	269.9	273					10	1140		
1125	270	tar	2f1.6	271.7	272.9	270.1	273	63	47.5	1.392	1.83	10	1140		
1130															

25.7 hr Entrainment Time

ITEM	Before Test 0.3 µ DOP Pene %	ΔP in. WC	Flow CFM	Before Test 0.6 µ DOP Pene %	ΔP in. WC	Flow CFM	After Test 0.3 µ DOP Pene %	ΔP in. WC	Flow CFM	After Test 0.6 µ DOP Pene %	ΔP in. WC	Flow CFM
Separator	97		1000	96	0.68	712	98		1000	96	0.68	712
				95	0.85	1140				92	0.79	1140
				90	1.26	1425				90	1.22	1425
HEPA-12	0.005	0.88	1000				0.004	0.88	1000			

TABLE D4 - AAF SEPARATOR
AVERAGE CONDITIONS FOR ETF INCIDENT TEST-24

Item	Description	Value
1	HEPA Outlet Temperature, F	271.1
2	HEPA Inlet Temperature, F	271.1
3	Separator Outlet Temperature, F	271.5
4	Separator Inlet Temperature, F	271.1
5	Spray Water Temperature, F	272.6
6	Heat Exchanger Outlet Temperature, F	273.4
7	Heat Exchanger Inlet Temperature, F	272.5
8	System Pressure, psig	47.3
9	HEPA Pressure Drop, inches WC	1.08 dry-1.34-1.40 ma
10	Separator Pressure Drop, inches WC	1.76 min-1.83-1.89 ma:
11	System Flowrate, CFM	1140
12	Separated Entrainment:	
	115 μ MVD, lbs/hr	≥50 and ≥100
	70 ÷ 10 μ MVD, lbs/hr	0
	10 μ MVD, lbs/hr	<1
13	Penetrated Entrainment (Dropout):	
	115 μ MVD, lbs/hr	0
	70 ÷ 10 μ MVD, lbs/hr	--
	10 μ MVD, lbs/hr	0

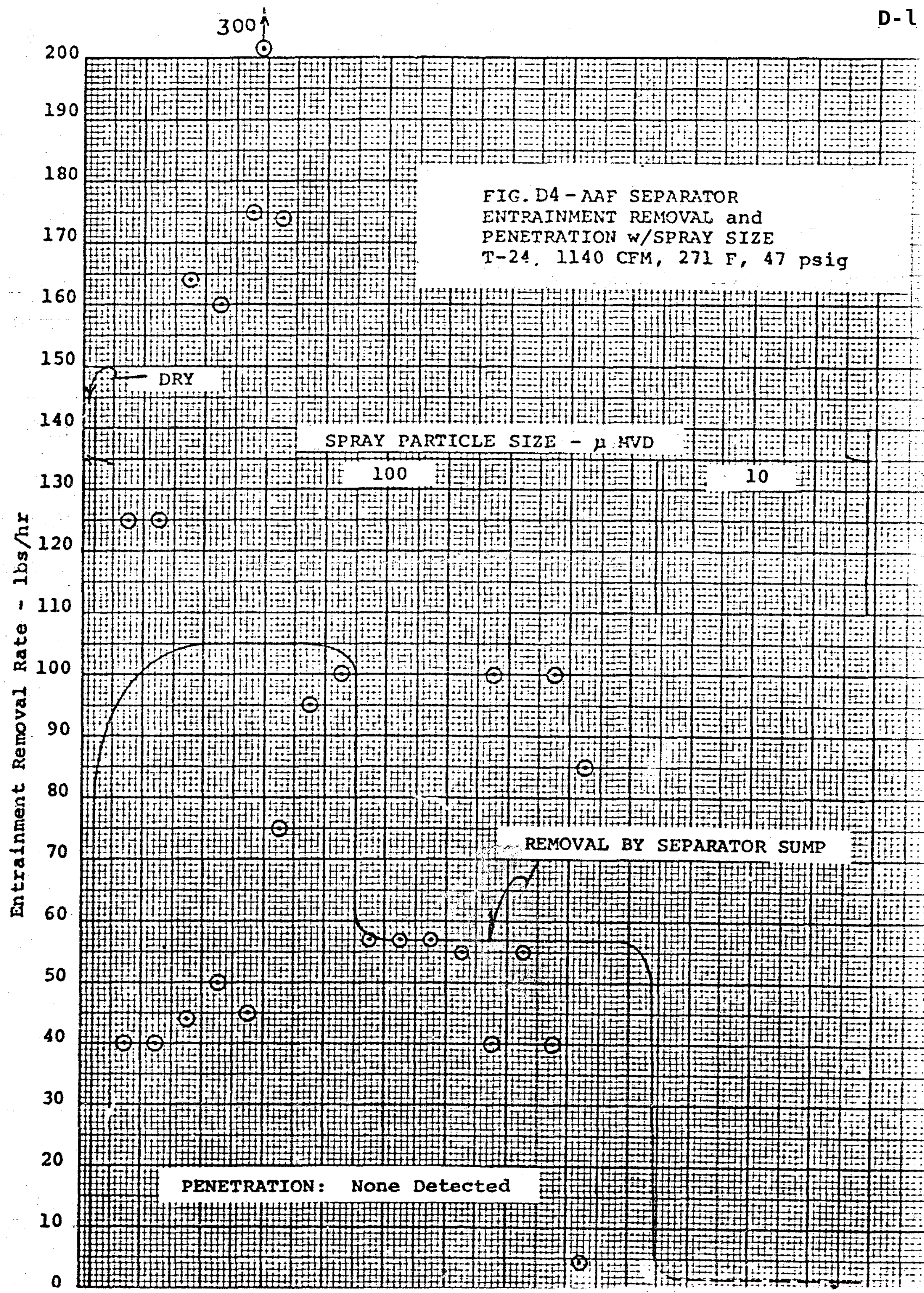


FIG. D4 - AAF SEPARATOR
ENTRAINMENT REMOVAL and
PENETRATION w/SPRAY SIZE
T-24, 1140 CFM, 271 F, 47 psig
Entrainment Removal Rate - lbs/hr
300
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
DRY
SPRAY PARTICLE SIZE - μ MVD
100
10
REMOVAL BY SEPARATOR SUMP
PENETRATION: None Detected

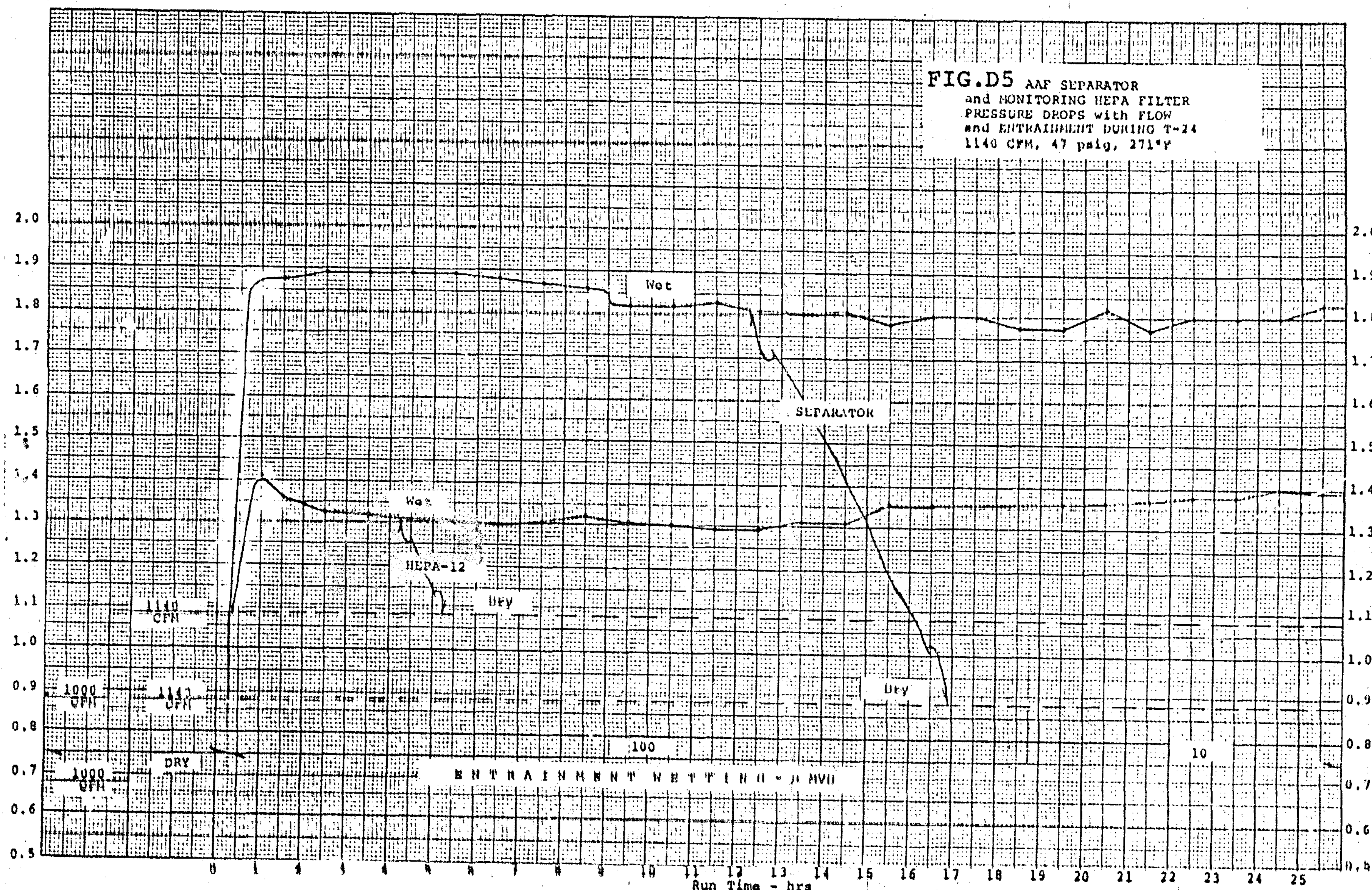


FIG.D5 AAF SEPARATOR
and MONITORING HEPA FILTER
PRESSURE DROPS with FLOW
and ENTRAINMENT DURING T-24
1140 CFM, 47 psig, 271°F

from 70 micron MVD at start-up to 115 micron MVD at incident, based on tabulated values for nozzle pressure drops resulting with 80 psig supply to nozzles and 5 to 47.7 psig in the system spray area.

Separator fibers were again observed streaming out from the back of the separator. Some fibers seemed to reach the HEPA face, 7 in. downstream of the separator. The fiberglass mat in the separator was bowed out >1/2 in. between the retainer grid openings. All fibers were soon a much darker brown in color from their original light yellow-green appearance. Many small brown liquid droplets were observed clinging to the fibers streaming out of the back of the separator; their quantity did not appear to increase enough to drop off these fibers and disappeared by evaporation within 6-8 hours. The separated entrainment water, removed through the rotometers, was visibly brown in color. Matted clumps of fiberglass were found in the lower drain reservoir section of the separator following this test.

No entrainment penetration of tie separator was visible or detectable by impactor sampling. No reentrainment penetration dropout was observed or measured. The defective weld areas in the lower corners of the separator drain section had been sealed with RTV-108 and gave no sign of leakage, A water level was observed behind the fiberglass pads at the outlet of the separator; it did not get high enough to flow over the outlet retainer flange.

Separated water removal rates were not constant through the rotometers. They fluctuated widely at constant entrainment loading, With the 18 TX-l nozzles operating to generate an entrainment loading of ≥100 lbs/hr, rotometer readings varied from 40 to 300 lbs/hr as shown in Table D3 and in Figure D5. Separator removal rate seemed to decrease slowly to the low values, then increase abruptly to the higher values, Removal rates seemed to indicate partial plugging of the drain sections with fiberglass, resulting in gradual internal accumulation af water which then drained at rates greater than entrainment loading values.

Entrainment loading was reduced to ≥50 lbs/hr of approximately 100 micron MVD particle size by using only one bank of 9 TX-1 nozzles. This occurred following the 18:00 reading in Table D3 and at the 9-hour run-time on Figures D4 and D5. Separated water drain rates became more constant with only occasional excursions, as shown in Table D3 and Figure D4. There was no further visible water level behind the separator pads. All other observations remained the same as at the initial higher entrainment loading, There was no visible or measurable entrainment penetration during this extended period of operation. HEPA differential pressure remained essentially constant at 1.3 in, WC after the initial peak 'of 1.35 in. WC when incident conditions were first attained, Separator differential pressure decreased slightly to 1.81 in. WC from the initial sustained level of 1.89 with twice the

Relative humidity effect of annular sprays was checked shortly after 24:00 (see Table D3) or 14.5 hours run-time (see Figure D4). Sixteen TX-1 nozzles, installed at the top of the annulus above the separator, were used. Spray direction was toward the HEPA, countercurrent to circulating air flow, as shown in Figure 1. After one-half hour of annular-spray operation, drops of water were observed falling from the top of the inner duct above the separator outlet with some being carried into the HEPA. Annular spraying was discontinued at this point where leakage other than entrainment penetration could jeopardize the separator test. A slight (4%) increase in the HEPA differential pressure from 1.31 to 1.36 in. WC was noted. The relative humidity increased approximately 1.75% to 97.42% at 270.7 F wet bulb and at 272.3 F dry bulb from the initial 95.67% at 269.9 F wet bulb and at 272.6 F dry bulb. During the balance of ≥ 50 lbs/hr of 100 micron MVD loading, the HEPA differential pressure remained constant at 1.36 in. WC and the separator differential pressure decreased slightly to 1.78 in. WC from 1.81.

Fine (10 micron MVD) loading was started at 0500 (Table C1) and 18.8 hours run-time on Figures D2 and D3. It was continued for about 6.5 hours, including one-half hour interruption for a steam filter gasket replacement. The TX-1 nozzles were shut off and 10-15 psia steam was used to operate 8 or 13 1A atomizing nozzles. Though a fairly dense fog was visible entering the separator, no penetration was detected and mass removal by the separator was below limits of measurement: ≤ 2 lbs/hr. During this 10 micron MVD test period, there was no detectable penetration, not as visible fog reentrainment, as measured (2-10 micron) impactor samples or as reentrained dropout. A slight pressure-drop increase of 3% (1.36-1.40 in. WC) was detected for the monitoring HEPA and an increase of <3% (1.78-1.83 in. WC) for the separator.

D.5.2 HEPA Monitoring Summary of Incident Test

HEPA pressure drop at 1140 cfm test flow rate increased 30% from 1.08 in. WC at ambient to 1.41 as incident conditions were reached with entrainment loading of ≥ 100 lbs/hr, 100 micron MVD. This differential pressure levelled out at 1.3 in. WC (20% increase from standard air) for the 100 micron MVD operation over the range of 50-100 lbs/hr. A 6% increase occurred during annular-spray test leakage; and a 4% increase back to 1.4 in. WC (30% above ambient) was observed during the balance of fine (10 micron MVD) particles at low (≤ 2 lbs/hr) loading. There was no significant change in final 0.3 micron DOP-differential pressure values of HEPA following the test. Integrity of the HEPA had been preserved by the AAF Separator under this range of incident operation and for the 16-hour ambient tests previously conducted using this same HEPA filter.

D.5.3 Separator Performance Summary of Incident Test

The AAF Type T Separator pressure drop at 1140 cfm rated flow increased 115% from 0.88 in. WC at ambient to 1.89 at incident with ≥100 lbs/hr of 100 micron MVD entrainment loading. This differential pressure decreased only slightly (105% above ambient) at lower entrainment loading (50 - 2 lbs/hr). Fine (10 micron MVD) particle size-operation indicated a slight final-in--crease to 108% above ambient.

Separator entrainment penetration was below detectable limits during this entire period of operation. There was no visible fog or reentrainment penetration,, no measurable reentxainment drop-.. out, nor any 2.5-10 micron-particle capture by impactor sampling (Section 6) of the separator effluent. Defective separator corner welds were sealed with RTV-108 and showed no further leakage. Droplets, initially visible on fiberglass strands outside-the separator, evaporated within 6-8 hours.

Separated entrainment removal water was largely erratic as indicated by rotometer removal rates, particularly at-the ≥100 lbs/hr, highest rate.tested. Partial plugging or other restriction of the separated water removal sections was indicated. A water level, close to overflowing the separator outlet flange, was observed at this time. No water level was visible at lower entrainment loading rates. Removed entrainment water-from the-separator was dark brown in color.

The fiberglass pad at the separator-outlet also turned dark brown from its original light yellow-green-color. The non-woven pad protruded 1/2 in. beyond the retainer grids at the separator outlet. Many (50-100) of the single glass strands broke loose from this pad to extend up to 7 inches downstream of the separator outlet face. Several clumps of matted fiberglass strands were visible through the 2 in. water drain opening into the separated water drain reservoir at the bottom of the separator, following Test Run T-24. These signs Of fiberglass packing deterioration did not affect final 0.6 micron DOP penetration measurements. The 0.6 micron DOP penetration remained essentially the same as measured before incident and before ambient tests, within limits of accuracy at these higher penetration levels.

D.6 CONCLUSIONS - INCIDENT TEST

The AAF Type T Mist Extractor, as described and tested, is adequate for HEPA protection service: Entrainment removal efficiency was essentially 100% down to 2.5 micron particle size, based on no detectable penetration down to<2 lbs/hr of 10 micron MVD entrainment loading. Entrainment loading of ≥100 lbs/hr, 1.5 lbs/1000 cu ft in the 100 micron MVD size range is permissible.

predicted from this test because of erratic entrainment removal rates experienced and because of visible water level near-the outlet flange observed at maximum loading tested. Suggested temperature limit may be 271 F as tested. This is based on the apparent degradation of the binder in the fiberglass pads.

E. MSA TYPE G SEPARATOR

An MSA Type G Moisture Separator was'selected for evaluation in this program. This separator gave no measurable penetration at ambient conditions and was also tested at incident conditions. It had been originally tested6 at 580 micron MVD entrainment service. Prior to ETF revisions for 10 micron MVD testing, this separator was satisfactorily test-operated at the lower ~100 micron MVD size entrainment. Separator description and-test performance are presented in the following subsections,

E.1 DESCRIPTION

Appearance: See Figures. 35 and 36. for--photographs,

Type: "G", MSA Separator Designation..
1234, Model number.
ASK-1743-1234-7, Assembly drawing.
Knitted mixed-fibermedia packing, retained by grids on both faces, enclosed in a frame with flanges all around for gasket sealing and with lower entrainment removal provisions for horizontal gas flow.

Size: 24 in. W x 24 in. H x 5 in. D, overall.
3/4 in. wide flanges, all around both faces.
3.5 sq ft face area, inlet and outlet.
1/2 in. 'diameter - 3 drain holes in lower outlet dorner.

Materials: Fiberglass fibers (9 μ) and Type 304 ss wire (0.006 in-.) with 16 gage ties as required.
Type 304 ss 16 gage case and grids,

Assembly: All welded case and grids.
Multiple layers of knitted media, arranged for service requirements, laced with the tie wires as required.

Weight: 30 lbs

Rating: 1600 cfm rated flow; 1000-2000 nominal flow range.
1.0 in. WC ΔP clean, dry at 1600 cfm ambient air.
1.5 in. WC ΔP clean, wet at 1600 cfm ambient air.
2.0 in. WC ΔP clean, wet at 1600 cfm incident air.

Rating: (cont.)
- 20 in. WC ΔP maximum recommended
- 650 lbs/hr, 6.8 lbs/1000 cu ft, maximum tested entrainment loading.
- >99.9% removal efficiency above 10 micron particle size
- >99% removal efficiency in 1-10 micron particle size (adequate for HEPA protection)
- >10% removal efficiency based on 0.6 micron DOP (nominally 80 ± 5% penetration)

E.2 ETF INSTALLATION

The MSA Separator was installed in the ETF with general arrangement as shown in Figure 1. The separator inlet flange was gasket-sealed to position the separator above the' separator case sump, so that the entrainment removed by the separator would drop into this sump for measured removal. The 5 in. deep separator extended to within 3 in. of the end of this separated water collection sump area as divided by the inner duct gasket. This 3 in. downstream duct section was not fitted for reentrainment collection based on prior tests which indicated no penetration beyond the downstream face of the separator.- For ambient tests, the 7 in. long Plexiglass sight section with collected water removal provisions was used. This was followed by the final 3.2 in. long penetrated water collection sumps. Thus, the distance from the outlet face of the Separator to the inlet face of the HEPA was 22 in. for ambient tests, and 15 in. for incident tests, omitting the Plexiglass section.

E.3 TEST RESULTS AT AMBIENT CONDITIONS

The MSA Type "G" Separator as described and installed was operated at ambient conditions during ETF Run T-19 in accord with the general test plan of Section 4. Summarized data are presented in Tables El and E2 and in Figures El, E2 and E3, with additional observations as follows-

E.3.1 ETF Ambient Test Observations

Air circulation rate was started at 1000 cfm to get a differential pressure profile at HEPA rating. It was then increase to the separator rating of 1600 cfm for this differential pressure profile and held at rated separator flow for the balance of testing under entrainment conditions, Cooling water to the heat exchanger was adjusted as required to keep the circulating air stream temperature from escalating. A series of photographs was-taken to illustrate separator installation and operation. Impactor samples were taken during 10 micron MVD operation, as discussed in Section 6; no 1-10 micron particle penetration was detected.

TABLE El - *MSA* SEPARATOR PERFORMANCE DATA

ETF Test-22
November 24, 1970
Atmospheric Pressure
RH: 98% start, 100% @ 1713

Time	Temperatures °F							Pressures			Spray	Flow Rates		
	HEPA		Separator		Heat Exchanger		Spray Water	Spray Water psig	Pressure Drop inches WG		Size u MVD	Gas Stream CFM	Separator Removal lbs/hr	Separator Penetration
	Out	In	Out	In	Out	In			HEPA	Separator				
0823									0.9	0.44		1000		
0827	Ambient							0	1.52	0.91		1600	Dry	
0848	92.5	91.5	91.5	94.5	95.5	94	93	40	1.52	0.93	100	1600		↑
0902	92	89.5	89.5	93.5	98.5	96.5	95	40	1.62	0.97	100	1600	45	
0915							96	40	1.62	1.0	100	1600	107.5	
0933	91	89	89	91	96	97	94	40	1.62	1.02	100	1600	232.5	No
0955	92.5	90	90	90.5	97	98.5	95	40	1.65	1.03	100	1600	344	
1015							80	40	1.66	1.04	100	1600	421.5	Visible
1036	90.5	88	88	88	96.5	97	76	40	1.66	1.05	100	1600	456	
1055	90.5	87.5	87.5	87.5	93	97	74	40	1.69	1.06	100	1600	486	or
1115							73	80	1.69	1.12	70	1600	622.5	
1134	76.5	83	83	84	88	87	73	80	1.65	1.21	70+10	1600	651	Measured
1207	84	81.5	81.5	82	86	84.5	73	80	1.69	1.27	70+10	1600	690	
1242							73	80	1.67	1.32	70+10	1600	641	Penetration
1313	84	81.5	81.5	82	86	84.5	73	80	1.68	1.38	70+10	1600	643	
1340	83.5	81.5	81.5	81.5	86	84.5	73	80	1.68	1.40	70+10	1600	642.5	
1412	92	90.5	90.5	91.5	93	91		8+2	1.75	1.27	10	1600		
1450	93	91.5	91.5	92.5	94	93		Air	1.73	1.12	10	1600	2.31	
1616	92	90.5	90.5	92	93	92.5			1.70	1.06	10	1600	2.5	
1649	92	90.5	90.5	91.5	93	92			1.74	1.06	10	1600		
1721								↓						↓

6.6 hrs Total Entrainment Time

ITEM	Before Test						After Test					
	0.3 μ DOP			0.6 μ DOP			0.3 μ DOP			0.6 μ DOP		
	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM	Pene %	ΔP in.WC	Flow CFM
SEPARATOR							96	0.42	1000	92 80 74	0.43 0.90 1.32	1000 1600 2000
HEPA-1	0.001	0.90	1000				.001	0.87	1000			

TABLE E2 - MSA SEPARATOR
AVERAGE CONDITIONS FOR ETF TEST-23

Item	Description	Value
1	HEPA Outlet Temperature, F	89.0
2	HEPA Inlet Temperature, F	87.6
3	Separator Outlet Temperature; F	87.6
4	Separator Inlet Temperature, F	88.7
5	Spray Water Temperature, F	82.5
6	Heat Exchanger Outlet Temperature, F	92.5
7	Heat Exchanger Inlet Temperature, F	92.0
8	System Pressure, psig	Atmospheric
9	HEPA Pressure Drop, inches WC	1.52 dry-1.66-1.76 max
10	Separator Pressure Drop, inches WC	0.93 dry-1.18-1.40 max
11	Separated Entrainment:	
	100 μ MVD, lbs/hr	45 to 486
	70 + 10 μ MVD, lbs/hr	651
	10 μ MVD, lbs/hr	2.5
12	Penetrated Entrainment (Dropout):	
	100 μ MVD, lbs/hr	0
	70 + 10 μ MVD, lbs/hr	0
	10 μ MVD, lbs/hr	0

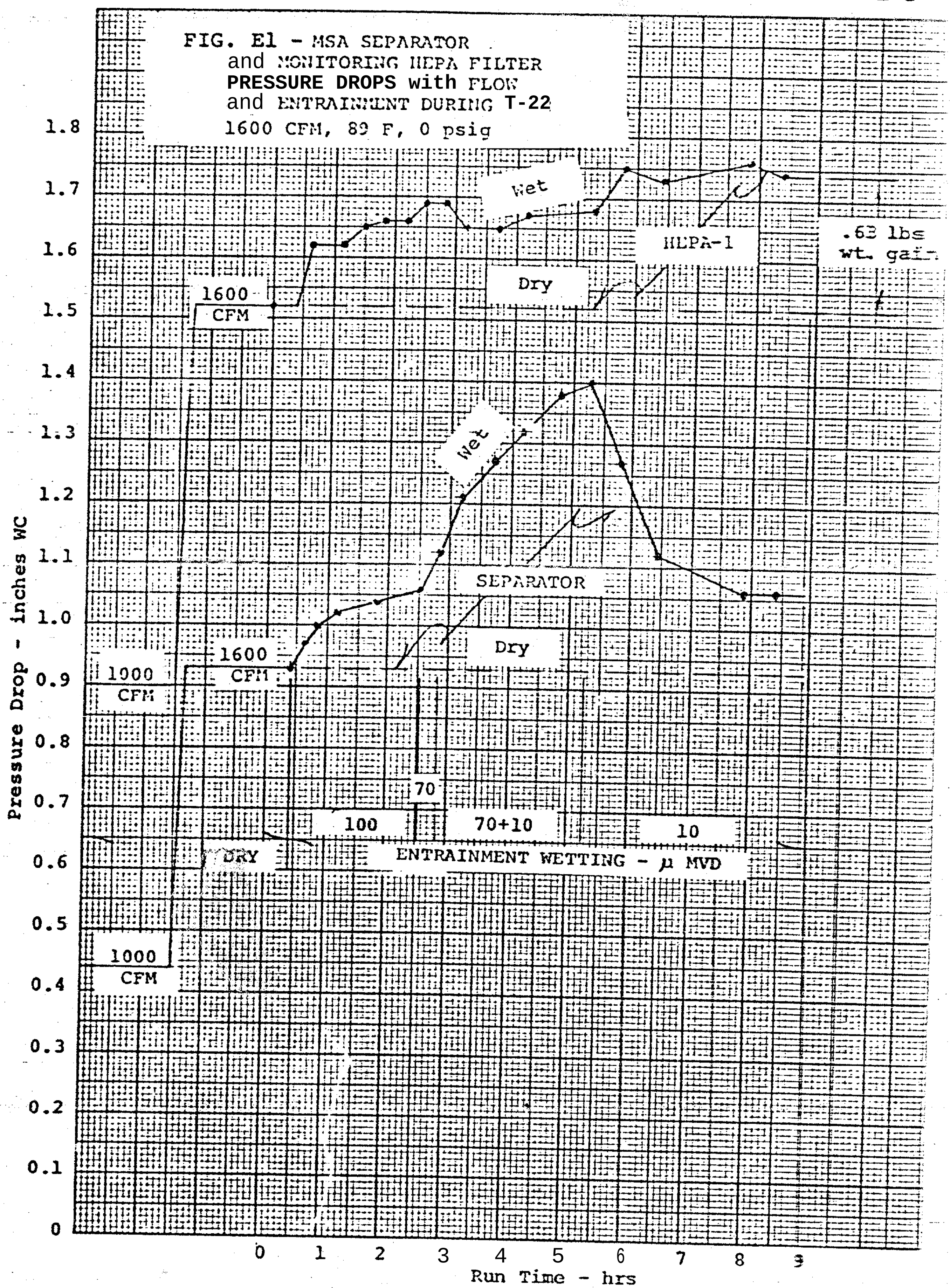


FIG. E1 - MSA SEPARATOR
and MONITORING HEPA FILTER
PRESSURE DROPS with FLOW
and ENTRAINMENT DURING T-22
1600 CFM, 89 F, 0 psig
Wet
HEPA-1
Dry
.63 lbs
wt. gain
1600
CFM
Wet
SEPARATOR
Dry
1600
CFM
1000
CFM
70
100
70+10
10
DRY
ENTRAINMENT WETTING - μ MVD
1000
CFM
Pressure Drop - inches WC
Run Time - hrs
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
0
1
2
3
4
5
6
7
8
9

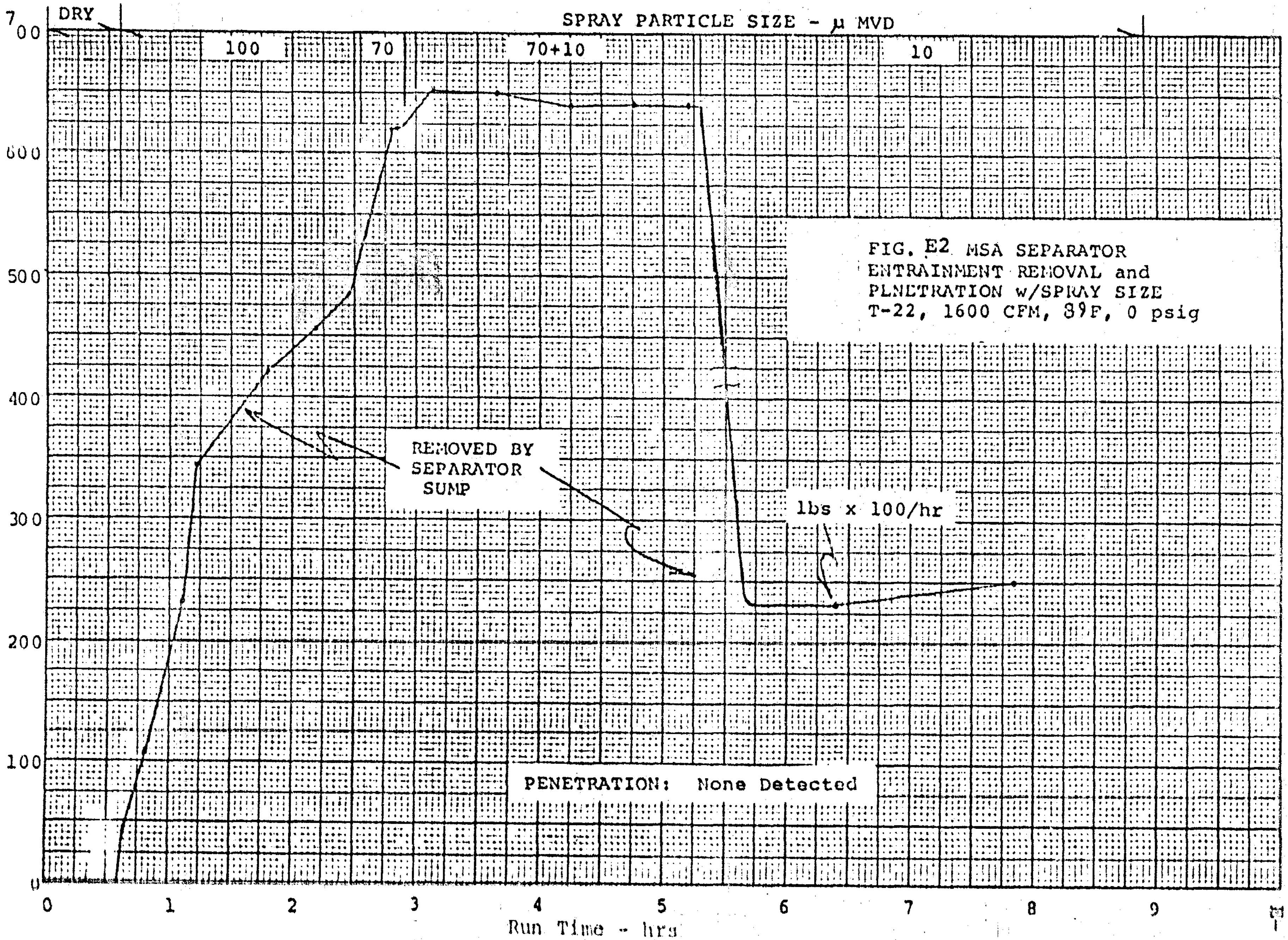


FIG. E2 MSA SEPARATOR ENTRAINMENT REMOVAL and PENETRATION w/SPRAY SIZE T-22, 1600 CFM, 89F, 0 psig

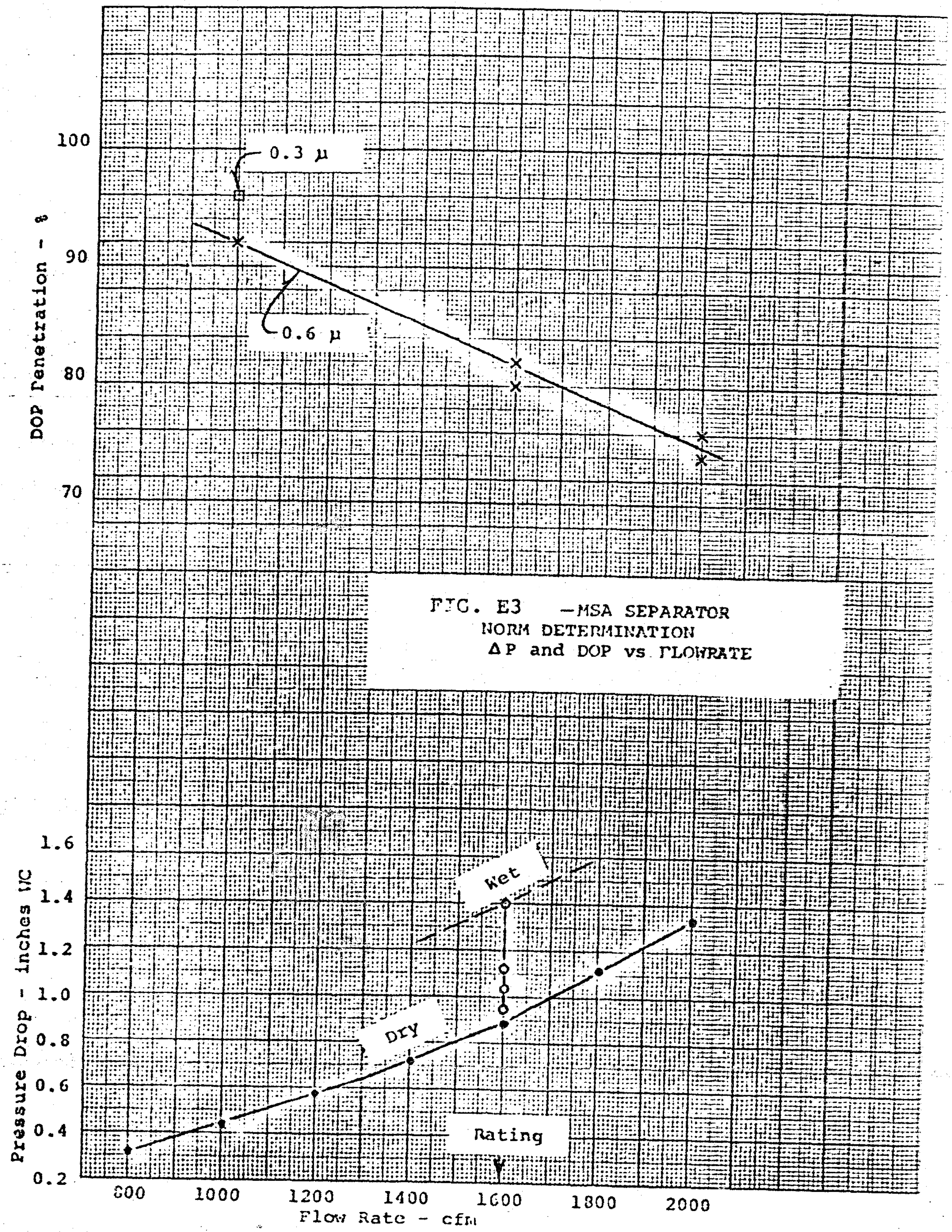


FIG. E3 —MSA SEPARATOR
NORM DETERMINATION
ΔP and DOP vs FLOWRATE

Entrainment was initiated at a low rate (45 lbs/hr) of-- large (100 micron MVD) particle size, using one bank of TX-1 nozzles operating at 40 psi. No penetration of fog or reentrainment was visible. Separated entrainment water drained cleanly, without splashing, from the lower rear separator drain holes into the removed water separator sump below. Large particle size entrainment loading was then increased in steps until all 108 TX-1 nozzles were in operation, yielding an entrainment removal rate. of 486 lbs/hr with no detectable separator penetration.

Fine (l-10 micron) distribution of mixes entrainment size was then increased-by- raising the TX-l nozzle pressure to 80 psi, approximately 70 micron MVD at 623 lbs/hr loading. To this, then, was.added the total output of 10 micron MVD particles from the thirty-nine 1A nozzles for a 651 lbs/hr maximum test loading of mixed size entrainment. No entrainment penetration of the separator was detectable at any time. Separated water removal was observed as steady streams entering the separated water removal sump directly below the separator, without splashing, despite a 2-3 in. fall. Within the separator, the water level was always well beiow the lower outlet flange. There was no visible change in media appearance throughout the test.

Further fine (l-10 micron) entrainment performance was checked by turning off all the TX-1 nozzles and leaving only the 1A nozzles in operation for 2.5 lbs/hr of 10 micron MVD entrainment loading. Aside from reduced separator differential pressure at the lower loading, no changes were detectable. The HEPA differential pressure seemed to be peaking out at 1.75 in. WC. No penetration of any type was detected: not by impactor sampling, visible observation, nor by collection in any of the penetration sumps.

E.3.2 HEPA Monitoring Summary of Ambient Test

HEPA pressure drop increased 15.8% frozl.52 in. WC at ambient and 1600 cfm to 1.76 in. WC maximum reached near the end of-the entrainment test, T-22. Rate of HEPA dif ferential pressure increase was fairly gradual (see Figure El) over the duration of the test run. One-third of the HEPA differential pressure increase occurred initially at low entrainment loading of large particles. The balance of HEPA differential pressure increase occurred without relation to increased entrainment loading or to decreased particle size. Total HEPA moisture gain was 0.6 lbs water by weight difference following test T-22. This was evaporated during final differential pressure-DOP tests following test operation.

E.3.3 Separator Performance Summary of Ambient Test

Pressure drop of the MSA Type G Separator, at 1600 cfm rated flow with ambient air only, was 0.93 in. WC as shown in Figure El. This was increased proportional to entrainment loading, reaching 1.4 in. WC (51% increase over ambient) ...

period of operation at maximum test loading of 650 lbs/hr, 6.8 lbs/1000 cu ft. Reduced loading to 2.5 lbs/hr of 10 micron MVD particles lowered the wetted separator differential pressure to 1.06 in. WC, a 14% increase over starting dry value. Flooding entrainment capacity was not reached in this test. No separator entrainment penetration was detected at any time during these test conditions.

E.4 CONCLUSIONS - AMBIENT TEST

The MSA Type G Separator performed an excellent job of entrain-nt separation under conditions tested. Removal efficiency was essentially 100% down to-2.5 micron particle size, based on no detectable penetration. Permissible entrainment loading capacity is 16.8 lbs/1000 cu ft of mixed particle size ≥70 micron + 10 micron MVD. Removal efficiency remains essentially 100% at entrainment loading 22.5 lbs/hr of 10 micron particles.

The 0.6 micron DOP penetration response,. ~82% penetration -- 18% removal efficiency, indicates probable removal efficiency for the larger l-10 micron water particles.

The MSA Type G Separator was considered suitable for additional performance testing at. incident conditions.

E.5 TEST RESULTS AT INCIDENT CONDITIONS

The MSA Separator, as described and tested at ambient conditions, was subsequently test operated at incident conditions of 271 F - 47 psig. This Separator test, T-23, served a two-fold purpose. First, to debug the ETF at incident conditions, with respect to the revisions made as discussed in Section 3.1. And next, to subject the MSA Separator to the fine (10 micron MVD) entrainment size under various conditions. An MSA Separator (S/N 1234-1) of this type had been previously tested (T-14) as satisfactory down to 75 micron MVD particle size. Thus ETF upsets, as problems arose during incident debugging, would not obscure any limitations of a separator having no prior operating history at these higher temperature-pressure conditions. Summarized data of this ETF test run (T-23) are presented in Tables E3 and E4 and in Figures E4 and E5, with additional observations as follows.

E.5.1 ETF Incident Observations

Following ambient tests of this MSA Separator as described in Section E.3, it was reinstalled (Section E.2) in the ETF, together with the same monitoring HEPA filter. Initial operation was with ambient air to get pressure drop reference profiles at 1000 and 1600 cfm, rated HEPA and separator flows.

TABLE E3 - MSA SEPARATOR PERFORMANCE DATA

CTP Tart-23
January 6-7, 1911
Incident: 271F-47 psig @ 29.35" Barometric
RH; %: 91 min.-95.8 Avg-98.8 Max

Run hr	Time	Temperatures °F HEPA Out	HEPA In	Separator Out	Separator In	Heat Exchanger Out	Heat Exchanger In	Spray Water	Pressures Spray Water psig	System psig	Pressure Drop inches WG HEPA	Pressure Drop inches WG Separator	Spray size μ MVD	Flow Rates Gas Stream CPM	Separator Removal lbs/hr	Separator Penetration
		168	165.4	154	172.9	182.5	174.6		10	Atmos.	0.90 1.55	0.45 0.88		1000 1603	Dry	
	1030			165.4					75	Increasing			75	600	Startup	
1	1100	261.6	259.9	259.9	260.6	260.7	260		75							
2	1200	271.2	269.7	269.1	210.2	212.6	211.4	241	75	46.5	1.348	1.49	125	1530	18	
3	1300	271	210	210	210.3	272.9	111.1	262	15	46	1.948	1.51	125	1530	55 TX-1	No
4	1400	271.5	270.6	270.6	270.9	273.9	272.5	268	75	41.5	1.824	1.55	125			
5	1500	271.5	271.8	271.8	272	275.2	274.1	272	75	47	2.044	1.72	125	1600	55	Visible
	1530	271	271.5	270.4	269.9	273.1	272.3	272	75	47.2	2.044	1.12	125	1530	52	
6	1600	271	272	271.7	271.2	274.6	273.8	272.5	75	47.2	[illegible]	[illegible]	115	600	25	or
7	1700	271	212	270.7	210.2	273.7	272.6	272.6	80	47.4	2.03	1.79	115	1600	33	
	1730	270	291	270.6	270.2	271.7	211.2	273	80	41.3	2.068	1.82	115	1600	29	9 Measureable
5	1800	271.5	212.5	271.5	272	273	272.4	273	80	48.-	2.136	1.66	115		X	
9	1930	270	271	270.1	271.6	274.6	273.6	273	80	47.5	2.196	1.88	115	1600	29	Penetration
				271.6	211.5		273.4	273		47.3	2.20	1.85	115	1400	21 TX-1	
10	5 2030	270	270	269.3	270.8	268.7	271.4	272		46.6	2.134	1.58	1000-	600	0 particles did	at
	2130	269	270	269.7	271.2	269.5	271.7	2725 Condensing Steam		46.6	2.12	1.49	10000	1600 not reach separator		
11	2200	270	271	8	271.1	274.2	273.1	212	80	47.0	2.12	1.95	115	1600	26	any
13	2300	210.5	271.5	212.1	212.9	273.3	274.6	272	80	47.2	2.128	1.83	115	1600	26 9	
14	2400 0100	271.25	271.5	269.7	269.28	276.3	272.148	272.5	80		2.132	1.84	115		TX-1	Time
						273		273	80	if.2	2.158	1.81	115	1600	27	
15	0200	271	272	270.8	-271.1	275.6	274.2	273	80	41.8	2.164	1.86	115	1600	27	
16	0300	210.5	271.5	270.4	270.7	274.2	273	273	80	47.3	2.172	1.65	115	1600	26	
									Steam	47.3	2.10	1.73	10	600		
17.5	0330 0430	272 211	273 2715	2272.5	2271.6	272.1	271.4	274	53	47	2.20	1.49	10	1600	<1	8-1-3 1-A
19.5	0530	211. 211.5	272.5 272	211.4 2724	269.9	269 2709	2128 212.3	274 274	54	48	2.16	1.52	10	1600		
									53	46.8	2.16	1.51	10	1600	Visible	
	0130	210.5	271.5	211.2	210.9	268.8	271.9	211	53	47	2.158	1.51	10	1600	Fog	
21	0800	271	272	271.7	271.6	271	271.1	271	53	47	2.128	1.52	10	1600	Entering	
22	0900	270.5	271.5	267.6	262.2	262.2	263.7	271	53	47.8	2.132	1.52	10	1600	Separator	
	0930	270	271	270.3	270	271.3	271.7		56	46.7	2.128	1.52	10			
	1030	270.5	271.5	271.4	271.1	271.2	271.2		54	46.1	2.124	1.52	10	1600		
24	1100													1600		

24.9 hrs Total Entrainment Time

ITEM	Before Test 0.3 μ DOP Pene %	ΔP in.WC	Flow CFM	Before Test 0.6 μ DOP Pene %	ΔP in.WC	Flow CFM	After Test 0.3 μ DOP Pene %	ΔP in.WC	Flow CFM	After Test 0.6 μ DOP Pene %	ΔP in.WC	Flow CFM
SEPARATOR	96	0.42	1000	92 80 74	0.43 0.90 1.32	1000 1600 2000				92 82 76	0.43 0.88 1.28	1000 1600 2000
HEPA-1	0.001	0.87	1000				0.001	0.90	1000			

TABLE E4 – MSA SEPARATOR
AVERAGE CONDITIONS FOR ETF INCIDENT TEST-23

Item	Description	Value
1	HEPA Outlet Temperature, F	270.8
2	HEPA Inlet Temperature, F	271.5
3	Separator. Outlet Temperature., F	270.1
4	Separator Inlet Temperature, F	270.8
5	Spray Water Temperature, F	271.9
6	Heat Exchanger Outlet-Tempera&e, F	272.2
7	Heat Exchanger Inlet Temperature, F	272.4
8	System Pressure, psig	47.2
9	HEPA Pressure Drop,.inches WC	1.55 dry-2.11-2.2 max
10	Separator Pressure Drop, inches WC	0.88 dry-1.67-1.88 max
11	System Plowrate, CFM	1600
12	Separated Entrainment:	
	125 µ MVD, lbs/hr	55
	115 µ MVD, lbs/hr	28
	10 µ MVD, lbs/hr	<1
13	Penetrated Entrainment (Dropout):	
	125 µ MVD, lbs/hr	0
	115 µ MVD, lbs/hr	0
	10 µ MVD, lbs/hr	0

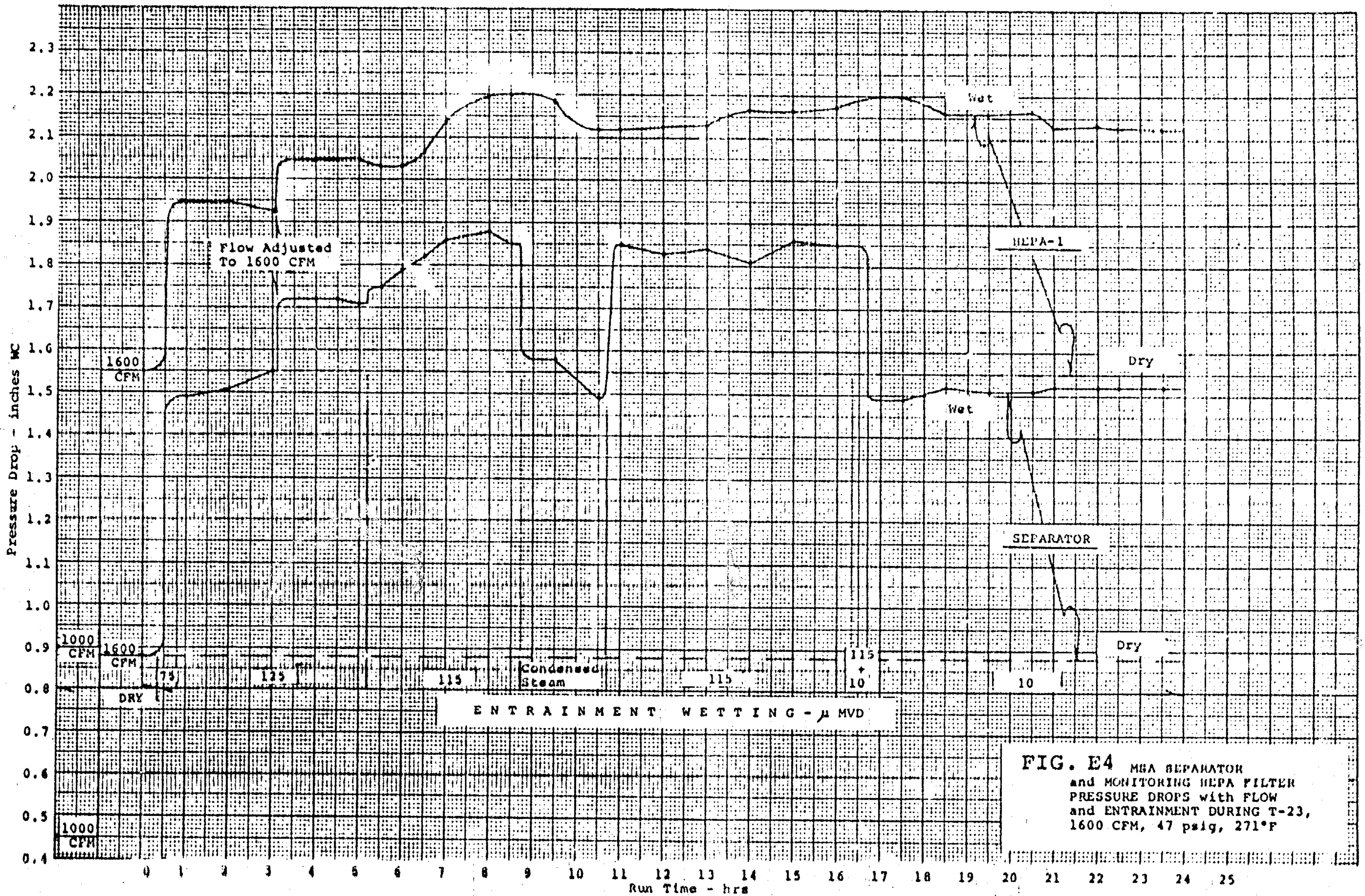


FIG. E4 MSA SEPARATOR and MONITORING HEPA FILTER PRESSURE DROPS with FLOW and ENTRAINMENT DURING T-23, 1600 CFM, 47 psig, 271°F

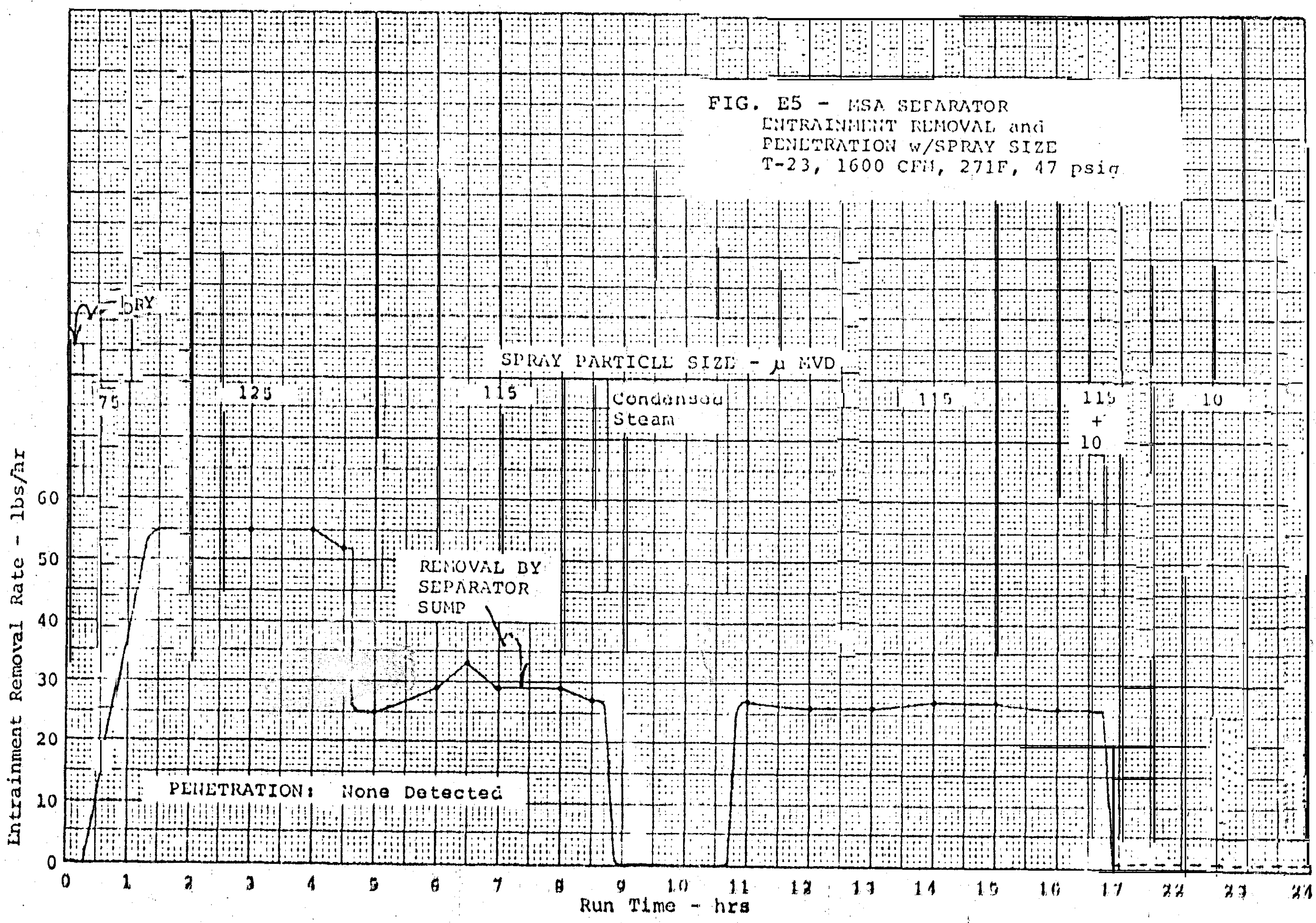


FIG. E5 - MSA SEPARATOR ENTRAINMENT REMOVAL and PENETRATION w/SPRAY SIZE T-23, 1600 CFM, 271F, 47 psig

ETF startup for incident conditions was begun by initiating large entrainment with two banks of TX-1 (18 nozzles) operating at 75 psig for approximately 75 micron MVD particle size. Heat-up was with the spray water heater and by the newly installed indirect steam heating of water in the bottom of the ETF. Several problems, including leakage, soon developed in the areas of ETF revisions made. Solving these obscured initial pressure drop profiles until flow rate was adjusted back to -1600 cfm as shown at 14:00 in Table E3, after three hours run-time on Figure E4. Pressure drops then reached 2.05 in. WC for the HEPA and 1.72 for the separator and remained at these values for the next 1.5 hours, during which incident temperatures were reached.

Large entrainment loading was reduced at 16:00, 4.5 hours -run-time, by turning off one, bank of TX-l nozzles. When removed entrainment. fell-to 25 lbs/hr, spray pressure was increased to 80 psig, 115 micron MVD at 30 lbs/hr loading. -Separator differential pressure increased from 1.71 to 1.79 in. WC and HEPA pressure drop fell from 2.05 to 2.03 in. WC by 17:00, 5 hours run-time.

Relative humidity effect of annular sprays was then tested. A bank of 16 TX-1 nozzles had been mounted in the annulus above the separator; discharge 'was toward the HEPA, 'into the return air stream. Pressure drop of the separator continued its previous rate of increase, reaching a maximum of 1.88 in. WC, 114% above ambient, and now the HEPA began to show a steady differential pressure increase (8%) from 2.03 to 2.2 in, WC, 42% above ambient. Water was observed leaking into the separator effluent stream from the annular spray area above. It was leaking through a defective duct seal weld;dropping on the impactor sample nozzle and splashing in the gas stream entering the HEPA. Annular sprays were secured following 1.5 hours of operation, and HEPA differential pressure remained at 2.2 in. WC. Relative humidity had increased about 1.3% in reaching 97.9% at 272.6 F dry bulb and 271.3 F wet bulb from its starting value before annular sprays of 96.3% at 273.7 F dry bulb and 271.6 F wet bulb.

Entrainment generated by condensing steam was tested next for a period of almost two hours -- 19:30-21530 in Table E3 and 8.7-10.7 hours run-time on Figures E4 and E5. All TX-1 nozzles were shut off and separator differential pressure promptly dropped from 1.85 to 1.58 in. WC and continued to fall to 1.49, 70% above ambient. HEPA differential pressure decreased from 2.2 to 2.12 in, WC, 37% above ambient, and remained at this value during this condensing steam period -of operation. Separator removal rate dropped to zero and no visible fog or large entrainment was seen reaching the separator, located about 5 ft downstream of the finned heat exchanger. The heat exchanger was operated over the range of 0.5 to 5 g-pm cooling water supplied at approximately 60 F. Heat removal duty was equivalent to condensing 40-400 lbs steam/hr at 270 F plus a 1-4 F gas stream temperature drop. This condensate was in the form of large (1000-10,000 micron) particles carried off all the cooler fins like a heavy rain. Most of the droplets landed within 6-12 in. downstream of the cooler. None were observed landing further than 24 in. downstream or remaining entrained beyond that point. Cooling rate did not visibly affect-the size of particles generated, only their concentration. While the cooler was in operation, the relative humidity showed a slight decrease from 97.9% (1.3°Δ DB-WB) to 95% (3.1°Δ DB-WB). Thus, reactor operation of this type is more likely to be at 95% relative humidity than at saturation (100%) values currently predicted.

Large entrainment test operation was resumed for an extended 6-hour period using one bank of nine-TX-1 nozzles at 80 psig (115 micron MVD, Figure ES). This gave a separator removal loading of 26.5 lbs/hr at 1.85 in. WC pressure drop. Penetration remained below limits of detectability. No visible fog or re-entrainment, no measureable reentrainment from the penetration sump, no significant change in HEPA pressure drop (2.12-2.17), and no detectable fine particle penetration measurable by the impactor were observed.

Fine (l-10 micron) particle distribution of mixed entrainment was initially- increased by turning on the steam to one bank of eight lA nozzles to test nozzle operation with steam. After 20 minutes (16.7 run-time hours on Figures E4 and ES), the TX-1 nozzles were turned off and only lA nozzles were used for better study of 10 micron MVD performance.. The output of the single bank of eight lA nozzles was observed as a stratified layer of fog in the central portion of the stream leaving the heat exchanger, together with an appreciable number of large droplet3 falling off the heat-exchanger fins and dropping out of the stream 8-20 in. downstream of the cooler. The fine mist was more dispersed before entering the separator; no large droplets were visible, Entrained fog density visibly increased when a second bank of lA nozzles (13 total) was activated. Attempts to use additional lA nozzles were unsuccessful because of the low steam pressure available -- because of the plant steam demend due to extremely cold weather. Operation was continued for the remaining seven hours of test time using 8 or 13 nozzles. No penetration was noted visually or by impactor measurements.

E. 5.2 HEPA Monitoring Summary of Incident Test

HEPA pressure drop at1600 cfm test flow rate increased 32% from1.55 in. WC at ambient to a maximum of 2.05 in. WC, reached at incident conditions including entrainment loading of 29-55 lbs/hr, 115-125 micron MVD size. Duct leakage during annular spray operation increased HEPA pressure drop to 2.2 in. WC maximum, 42% above ambient. This differential. pressure decreased to 2.12 in. WC at the-end of the 10 micron MVD testing at the <1 lb/hr removal rate. There was no final change in 0.3 micron DOP differential pressure values of the HEPA following this test, Integrity of the HEPA had been preserved by the MSA Separator under this range of incident operation and for the 8.6 hour ambient test previously conducted using this same HEPA filter.

2.5.3 Separator Performance Summary of Incident Test

MSA Type G Separator pressure drop at 1500 cfm rated flow increased 1145 froe 0.88 in. WC at ambient to a maximum of 1.88 reached at incident with 29 lbs/hr of 115 micron MVD entrainment loading. The differential pressure increase with higher loading was negligible (1% increase from 29 to 55 lbs/hr). At essentially wetted condition only, 0-l lb/hr loading, differential pressure decreased to 1.52 in. WC, 73% above ambient.

Separator entrainment penetration was below detectable limits during this entire period of operation:- There was no -- -- visible fog or reentrainment penetration, no measurable reentrainment penetration collection, nor any 2.5-10 micron particle capture by impactor sampling (Section 6) of the separator effluent gas. There was no visible change in separator appearance during and following this test. The 0.6 micron DOP response remained unchanged following incident test operation.

E.6 CONCLUSIONS - INCIDENT TEST

The MSA Type G Separator, as described and tested, is adequate for HEPA Protection service. Entrainment removal efficiency was essentially 100% down to 2.5 micron particle size, based on no detectable penetration dawn to <1 lb/hr of 10 micron MVD size entrainment loading.. Maximum entrainment loading tested was 55 lbs/hr, 0.57 lbs/1000 cu ft of 125 micron MVD particle size; Since the separator had handled 6.8 lbs/1000 cu ft at ambient conditions, it is assumed the same load could have been handled at incident conditions.

END

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